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CYCLOPEDIA
OF
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A Manual of
STEAM BOILERS, STEAM PUMPS, STEAM ENGINES, GAS AND
OIL ENGINES, MARINE AND LOCOMOTIVE WORK, RE-
FRIGERATION, HEATING AND VENTILATING, MACHINE
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◆

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American Institute of Electrical Engineers.

Authorities Consulted

THE editors have freely consulted the standard technical literature of Europe and America in the preparation of these volumes. They desire to express their indebtedness, particularly to the following eminent authorities, whose well known treatises should be in the library of every engineer.

Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms, in making these volumes thoroughly representative of the best and latest practice in the design and construction of steam and electrical machines and machine tools; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

FRANCIS BACON CROCKER, M. E., Ph. D.

Head of Department of Electrical Engineering, Columbia University; Past President American Institute of Electrical Engineers.
Author of "Electric Lighting," "Practical Management of Dynamos and Motors."

SCHUYLER S. WHEELER, D. Sc.

Electrical Expert of the Board of Electrical Control, New York City; Member American Societies of Civil and Mechanical Engineers.
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Author of "Strength of Materials," "Mechanical Engineer's Pocketbook," "Steam Boiler Economy," etc.

◆

DUGALD C. JACKSON, C. E.

Head of Department of Electrical Engineering, University of Wisconsin; Member of American Society of Mechanical Engineers; American Institute of Electrical Engineers.

Author of "A Textbook on Electro-Magnetism and the Construction of Dynamos," "Alternating Currents and Alternating Current Machinery."

◆

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KEMPSTER B. MILLER, M. E.

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Instructor in Machine Shop Work, Rindge Manual Training School; formerly Superintendent Waltham Watch Tool Co.
Author of "The American Steel Worker."

* * *

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Late Professor of Descriptive Geometry and Drawing, Massachusetts Institute of Technology.
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THE Cyclopedia of Engineering is compiled from the most practical and comprehensive instruction papers of the American School of Correspondence. It is intended to furnish instruction to those who cannot take a correspondence course, in the same manner as the American School of Correspondence affords instruction to those who cannot attend a resident engineering college.

¶ The instruction papers forming the Cyclopedia have been prepared especially for home study by acknowledged authorities, and represent the most careful study of actual shop needs and conditions. Although primarily intended for correspondence study, they are in use as text books by Columbia University, Lehigh University, Iowa State College, the University of Maine, the U. S. Government in its School of Submarine Defense, the Westinghouse Companies in their Shop School, and for reference in the leading colleges, shops and public libraries.

¶ Years of experience in the shop, laboratory, and class-room have been required in the preparation of the various sections of the Cyclopedia. Each section has been tested by actual use for its practical value to the man who desires to know the latest and best practice in the shop or engine room.

❡ Numerous examples for practice are inserted at intervals; these, with the test questions, help the reader to fix in mind the essential points, thus combining the advantages of a text book with a reference work.

❡ Grateful acknowledgment is due to the corps of writers and collaborators, who have prepared the many sections of this work. The hearty co-operation of these men—engineers of wide practical experience and acknowledged ability — has alone made these volumes possible.

❡ The Cyclopedia has been compiled with the idea of making it a work thoroughly technical yet easily comprehended by the man who has but little time in which to acquaint himself with the fundamental branches of practical engineering. If, therefore, it should benefit any of the large number of workers who need, yet lack, technical training, the editors will feel that its mission has been accomplished.

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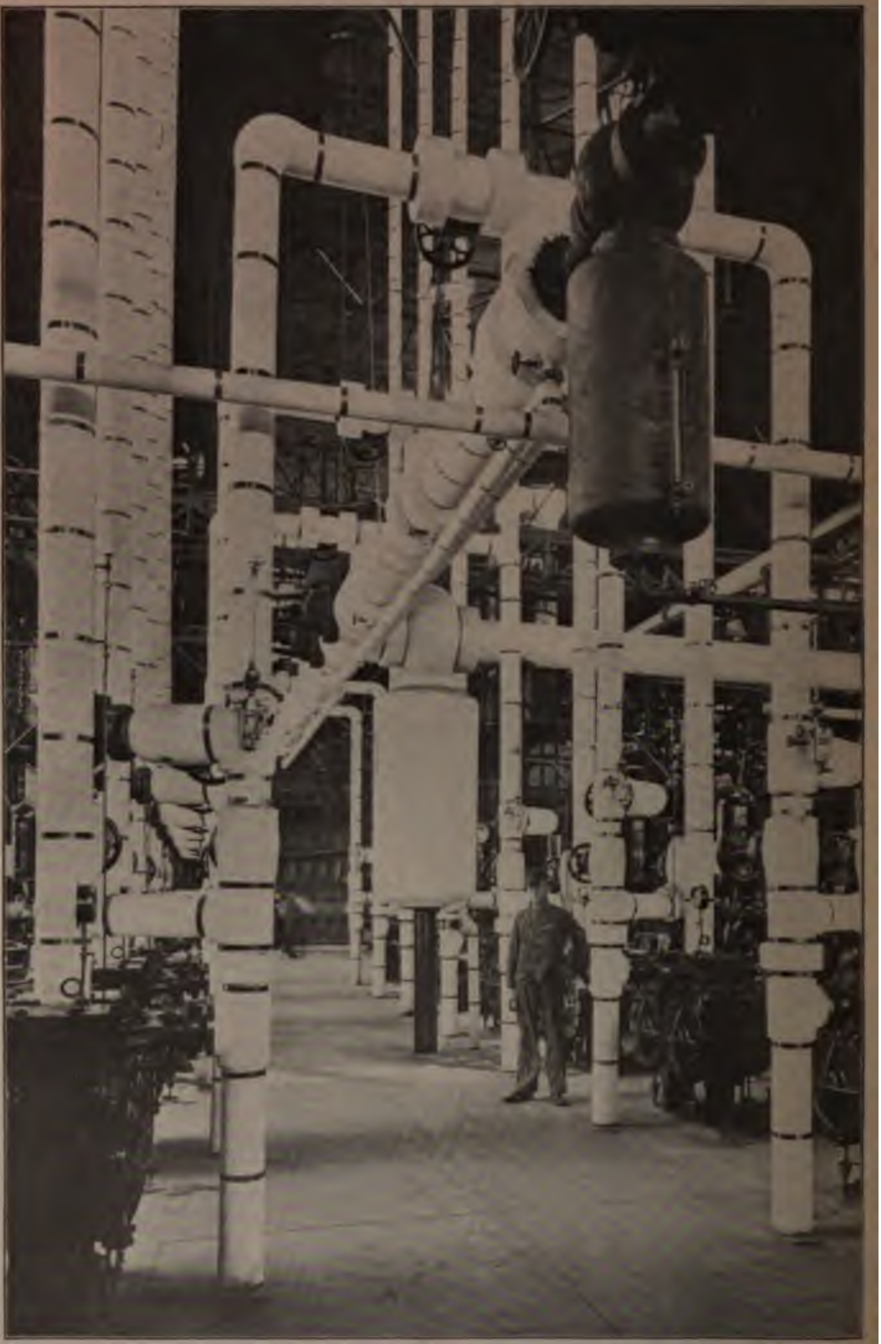

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HEAT.

Until the time of Count Rumford and Sir Humphry Davy the most widely accepted notion of the nature of heat was that it was an elastic fluid, penetrating the pores of all matter and filling the spaces between molecules. To this fluid the name caloric was given. In order to explain the various manifestations of heat, it was necessary to ascribe various properties to the caloric fluid, such as indestructibility, absence of weight, differences in the intensity of its affinity for different kinds of matter, and so on. But these explanations were not borne out by experiment; and in 1798 Count Rumford showed, by a series of experiments with a blunt boring bar and a brass cannon, that the heat developed in boring the cannon had no relation to anything but the friction of the apparatus. He thus proved that heat could not be a material substance, for it was produced without limit from a limited quantity of matter, provided only that the motion were maintained; and he announced his conviction that heat was in reality a form of motion.

Sir Humphry Davy showed that two pieces of ice might be melted by rubbing them together. He thus proved that heat can be produced by the expenditure of work only. This leads to the important conclusion that heat must be a form of energy, since it can be produced from energy, and (as we know in the case of the steam engine) can itself be converted into well-recognized forms of energy.

Heat-energy is now understood to lie in the rapid irregular vibrations of the molecules of which all matter is composed. We shall see that the idea of rapidly-moving molecules affords a ready explanation of many of the phenomena of heat.

This motion may be communicated from one body to another: or, in other words, heat may flow from one body to another. The condition that determines which way the flow will take place is called **temperature.**

Temperature, then, has nothing to do with quantity of heat. If a spoonful of water be dipped from a full pail, it is clear that the quantities of heat in the two masses of water are very unequal, yet there is no tendency for heat to travel from either to the other.

Our study of the phenomena and laws of heat thus naturally divides itself as follows:

1. The measurement of temperature, or thermometry.
2. The measurement of quantities of heat, or calorimetry.
3. The relation between heat and mechanical work, or thermodynamics.

Equality of temperature may be estimated quite accurately simply by touching two bodies with the hand, provided they are of a similar nature and neither very hot nor very cold. The power which enables us to do this is called the temperature sense. It does not help us much, however, if the bodies are of very different nature, nor does it tell us whether they are actually hot or cold. The sensation really depends on the rate at which heat is communicated to (or taken from) the hand, and this depends on the temperature of the hand as well as on the nature of the material tested.

A simple experiment will illustrate this. Place the right hand in ice-water and the left hand in hot water; after a minute withdraw them and place them simultaneously in water just drawn from the faucet. It will seem warm to the right hand and cold to the left hand, because in the first case heat passes from the water to the hand, and in the second case from the hand to the water. Again, a stone in winter feels colder to the hand than a piece of fur or woolen cloth. The stone conducts the heat away from the hand faster than the fur does, and thus gives the sensation of a lower temperature.

THERMOMETERS.

Instruments for the measurement of temperature are called **thermometers.** In designing a thermometer we may use any substance one of whose properties varies continuously with the temperature. Among the properties most convenient for use are:

1. Expansion; used for ordinary temperatures.
2. Change of electrical resistance; used for very low temperatures.
3. Thermo-electric effects; used for very high temperatures.

The first of these is discussed in this paper; the principles on which the others depend will be explained in the Instruction Papers on Electricity.

Besides these, many other properties of substances that depend on temperature are useful in special cases. For example, when a piece of polished steel is heated its surface changes color, each color corresponding to a certain definite temperature. The process of **tempering** consists in heating the previously hardened articles until they assume the proper temperature, as shown by their color, and then plunging them again into cold water or oil. In this way each piece is made to indicate its own temperature without possibility of mistake.

Liquid Thermometers. In the most common form of thermometer, temperature is measured by the expansion of mercury in glass. On the end of a glass tube of very fine bore, a bulb is blown (see Fig. 1), and the bulb and part of the tube are filled with mercury. The whole is then heated until the mercury completely fills the tube, after which it is sealed and allowed to cool. The space in the tube above the mercury is thus entirely freed from air. Changes in temperature cause the mercury to expand or contract, and the liquid in the tube will rise or fall accordingly.

But the thermometer thus made is not yet ready for use. It must have its divisions properly spaced and in the right places on the tube. All thermometers for accurate work should have their scales engraved on the tube itself, and not on a plate attached to it. Before we can engrave the scale we must know at least two points on the stem that correspond to known temperatures. The two points commonly taken are known as the **freezing point** and the **boiling point**.

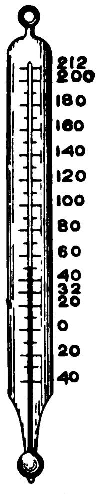

Fig. 1.

The freezing point can easily be found by putting the thermometer into a mixture of clean pounded ice (or snow) and water. The boiling point is found by immersing the whole thermometer in steam from boiling water. The freezing point is always the same under ordinary conditions, but the temperature of the boiling point rises or falls slightly as atmospheric pressure increases or decreases.

Thermometer Scales. Two scales of temperature are in use. On the ***Fahrenheit*** scale, devised about 1714, the boiling point is marked 212°, and the freezing point 32°, there being thus 180 degrees between them. The *Centigrade* scale, which is more convenient for scientific work, has its boiling point marked 100° and its freezing point marked 0°.

We may convert Centigrade to Fahrenheit temperatures in the following way :

Since 100 Centigrade degrees cover the same temperature interval as 180 Fahrenheit degrees, one Centigrade degree is $\frac{180}{100}$ or $\frac{9}{5}$ as long as one Fahrenheit degree. Hence a temperature of m degrees Centigrade is equal to $\frac{9}{5}m$ Fahrenheit degrees above the Centigrade zero. But this point is marked 32° on the Fahrenheit scale, consequently the total reading on the Fahrenheit thermometer will be

$$\frac{9}{5}m + 32.$$

The formula for changing a temperature C° Centigrade to its Fahrenheit equivalent F°, therefore, is

$$F^\circ = \frac{9}{5}C^\circ + 32;$$

and by transposing we obtain the corresponding formula,

$$C^\circ = \frac{5}{9}(F - 32).$$

EXAMPLES FOR PRACTICE.

1. To what temperature F does 58° C correspond?
Ans. 136.4° F.

2. To what temperature C does 149° F correspond?
Ans. 65° C.

3. The difference between the temperatures of two bodies is 45° F. What is it in Centigrade degrees?
Ans. 25° C.

4. Lead melts at 327° C. What is its melting point on the Fahrenheit scale? Ans. 620.6° F.

Temperatures below the zero point can be dealt with by calling them negative and using them with a minus sign.

Example. To what temperature F does — 20° C correspond?

Solution. $$F^\circ = \left(\frac{9}{5} \text{ of } -20\right) + 32$$

$$= -36 + 32 = -4^\circ. \text{ Ans.}$$

EXAMPLES FOR PRACTICE.

1. To what temperature F does — 18° C correspond?

Ans. — 0.4° F.

2. To what temperature C does — 40° F correspond?

Ans. — 40° C.

The temperature T_s of steam in Centigrade degrees is given by the following formula:

$$T_s = 100^\circ + \frac{3}{80}(H - 760),$$

where H is the barometric pressure in millimeters.

In Fahrenheit degrees the temperature T'_s is

$$T'_s = 212^\circ + 1.71(H'' - 29.92),$$

where H″ is the barometric pressure in inches.

When the barometer stands at exactly 760 millimeters or 29.92 inches, the temperature of steam is therefore 100° C or 212° F. The Centigrade scale is used in almost all scientific work, while the Fahrenheit scale is more common in daily life.

EXAMPLES FOR PRACTICE.

1. What is the temperature of steam when the barometer reads 772.8 millimeters?

Ans. 100.48° C.

2. What is the temperature of steam when the barometer on a mountain stands at 27.44 inches?

Ans. 207.76° F.

EXPANSION OF SOLIDS.

When the temperature of a body rises, as a rule we find an increase in its dimensions. This is called **expansion.** It depends on the rise of temperature and on the nature of the body itself. A rod whose length is unity at 0° C will have at any other temperature t the length

$$1 + a\,t,$$

where a is a small constant called the **coefficient of linear expansion.** If $t = 1°$, then the length at 1° would be simply

$$1 + a \times 1 = 1 + a,$$

and the increase in length would be

$$(1 + a) - 1 = a.$$

We may therefore define the coefficient of linear expansion as the increase in length per Centigrade degree of a rod whose length is unity at 0° C. It varies a little at different temperatures and is usually larger at higher temperatures.

The following table gives the average value of the coefficient of linear expansion for various solids, between 0° and 100° C (32° to 212° F). Different specimens of the same substance sometimes give different results, and the figures do not hold for temperatures much beyond the given limits. They may, however, be used for all ordinary purposes.

COEFFICIENTS OF LINEAR EXPANSION.

	PER DEGREE CENTIGRADE.	PER DEGREE FAHRENHEIT.
Porcelain	0.00000806	0.00000448
Gas carbon	0.0000055	0.0000031
Glass	0.0000057 to 0.00000883	0.0000032 to 0.00000491
Pine wood, along grain	0.00000608	0.00000338
Cast iron	0.00001075	0.000005972
Platinum	0.00000907	0.000005039
Steel	0.00001088 to 0.00001098	0.000006044 to 0.00000610
Wrought iron	0.00001228	0.000006822
Copper	0.00001666 to 0.00001718	0.00000925 to 0.00000954
Brass	0.00001840 to 0.00001906	0.00001022 to 0.00001059
Silver	0.00001943	0.00001079
Zinc	0.00002976	0.00001653
Ice	(— 12° to 0°), 0.0001050	(10° to 32°), 0.0000583

The coefficient of surface expansion may be found by multiplying the above figures by two; and the coefficient of cubical or volume expansion, by multiplying by three.

It is clear from the table that different substances expand very unequally ; zinc, for example, expanding over three times as much as platinum and more than twice as much as iron. If then

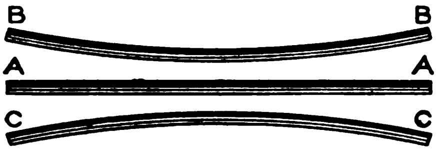

Fig. 2.

we make a bar like A of Fig. 2, by riveting together a strip of zinc and one of iron, and heat it, the bar will not only lengthen but become curved, the zinc being on the convex side. If cooled below its original temperature, the bar curves the opposite way ; and by fixing one end of the bar the other end may be made to show a considerable motion for small changes of temperature.

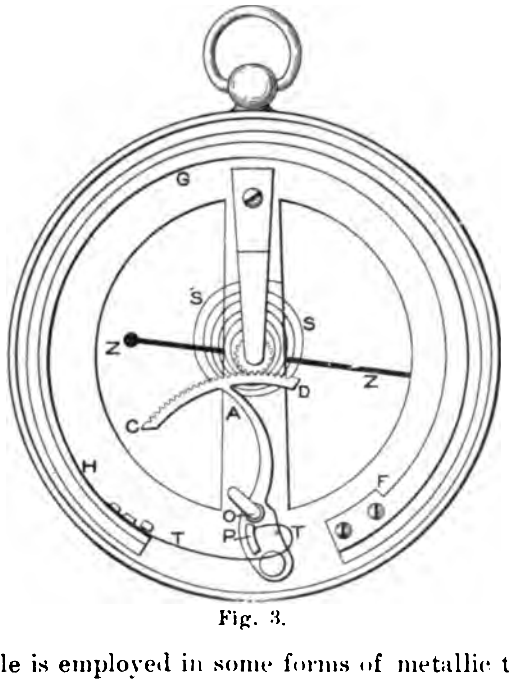

Fig. 3.

This principle is employed in some forms of metallic thermometer (see Fig. 3). The metal spring F G H is fastened at F, the remaining part being free to expand or contract. To this spring, at H, is fastened a finer spring T T, clamped at P to the arm A,

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which is pivoted at O. The segment C D of a gear on the arm A operates the pinion to which the hand Z Z is attached. An additional spring S S tends to move the hand in the opposite direction. Heat causes expansion of the spring F G H, and the hand Z Z moves in a direction opposite to that of the hands of a clock. The same principle is also used in thermostats. In these instruments the free end of the bar is sometimes made to move between stops connected with electric circuits; and in this way the temperature of a furnace or a room can be easily controlled.

With the help of the table we can calculate the expansion of a rod of any length. Let l_0 represent the length of a rod at 0° C, and l_t its length at the temperature $t°$; and let us find the relation between l_0 and l_t.

Since a rod of unit length at 0° will have at $t°$ the length $1 + a\,t$, the length of a rod l_0 times as long will be l_0 times as much, or $l_0\,(1 + a\,t)$. That is,

$$l_t = l_0\,(1 + a\,t). \qquad (1)$$

By transposing, we may put this into the form

$$l_0 = \frac{l_t}{1 + a\,t}. \qquad (2)$$

Example. A copper wire is 65 inches long at 30° C. How long is it at 0° C?

Solution. From equation 2 we have:

$$\text{Length at } 0° = \frac{65}{1 + 0.00001666 \times 30}$$

$$= \frac{65}{1.0005} = 64.967 \text{ inches. Ans.}$$

Example. A sheet of zinc twenty inches by thirty is heated from 32° F to 100° F. What is its increase in area?

Solution. The surface expansion of zinc is 2×0.00001653, or 0.00003306 per degree F.

The surface of the sheet is $20 \times 30 = 600$ sq. in.

The sheet is heated through $100° - 32° = 68$ degrees F.

Therefore the area of the heated sheet will be

$$600\,(1 + 0.00003306 \times 68) = 600\,(1 + 0.002248) = 601.35.$$

The increase in area is therefore 1.35 sq. in. **Ans.**

EXAMPLES FOR PRACTICE.

1. A brass disk has a diameter of four inches at 32° F. What is its diameter at 72° F?

Ans. 4.00164 inches.

2. A copper tank holds ten gallons of ice water. How many gallons of boiling water will it hold?

Ans. 10.05 gallons.

Suppose the length of a rod to be given at a certain temperature $t°$, and we wish to find the length at some other temperature $t'°$. Inspection of equation 2 shows that we may write

$$l_{t'} = l_o\,(1 + at').$$

We also have directly

$$l_t = l_o\,(1 + at).$$

Dividing one equation by the other, we have

$$\frac{l_{t'}}{l_t} = \frac{l_o\,(1 + at')}{l_o\,(1 + at)};$$

or,

$$l_{t'} = l_t\,\frac{1 + at'}{1 + at} \qquad (3)$$

A more convenient form of this equation, which will give approximately correct results, is as follows:

$$l_{t'} = l_t\,[1 + a\,(t' - t)\,]. \qquad (4)$$

Equation 4 may be used to determine the length of a bar which has been heated through a known temperature, when the original length and the coefficient of expansion are known.

EXAMPLES FOR PRACTICE.

1. A rod of copper is 10 feet long at 25°C. What will be its length at 85°?

Ans. 10.01 feet, nearly.

2. A bar of wrought iron is 200 inches long at 40° F. What will be its length at 148° F?

Ans. 200.147 inches.

3. If the extreme difference between summer and winter temperatures is 100 degrees F, what will be the change in length of an iron bridge which is 250 feet long in summer?

Ans. 0.1705 foot shorter.

EXPANSION OF LIQUIDS.

In the case of liquids and gases we have to deal only with cubical expansion, since fluids have no definite form. The expansion of liquids is much greater than that of solids. For mercury the average coefficient between 0°C and 100°C is 0.0001825 per degree. For other liquids the expansion increases rapidly with the temperature and is very great at high temperatures. The following table gives some values for three common liquids.

TEMP.	WATER.	ALCOHOL.	ETHER.
0°	1.	1.	1.
10°	1.0001	1.0105	1.0152
20°	1.0016	1.0213	1.0312
30°	1.0041	1.0324	1.0483
40°	1.0076	1.0440	1.0665

Water presents a partial exception to the increase of volume by rise of temperature. As its temperature rises from 0° (ice just melted) to 4°C, it contracts instead of expanding, the amount of contraction being 129 parts in a million. Above 4° it expands like any other liquid.

This curious fact is of immense importance in nature. As the water of rivers and lakes cools, it becomes denser and sinks, the coldest water thus going to the bottom until 4° is reached. Below this temperature, however, the water becomes lighter as it cools, and stays at the surface. Ice thus forms first at the surface and the life beneath is protected, as ice is a poor conductor of heat. If the water contracted down to the freezing point, ice would form from the bottom up, and a pond would become a solid mass which would probably never thaw completely.

An interesting application of the expansion of liquids is in the mercurial pendulum used in large clocks (Fig. 4). The pendulum rod carries at its end a jar of glass or iron holding a quantity of mercury. A rise in temperature lengthens the rod and lowers the center of gravity of the pendulum; but the mercury also expands and rises in the jar, producing the opposite effect. In this way, by using the proper amount of mercury, it is possible to make a pendulum whose vibrations are unaffected by changes in temperature.

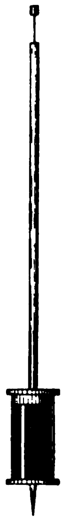
Fig. 4.

EXPANSION OF GASES.

If we partially fill a bladder with air and place it near a fire, it will become distended, showing that the air has expanded. This expansion is practically the same for all gases, and, for each degree, is $\frac{1}{273}$ or 0.00366 of their volume at 0°C; for each degree F a gas will expand $\frac{5}{9}$ as much, or $\frac{1}{491}$ of its volume at 32° F. These figures assume that the pressure on the gas remains constant.

If then we have a quantity of gas V at 0°C, at 1° it will have the volume $\frac{274}{273}$V, at 2° it will have the volume $\frac{275}{273}$V, and so on. We may express the general law as follows:

If V_0 be the volume at 0°C, then the volume V_t at any other temperature t will be

$$V_t = V_0(1 + \frac{t}{273}). \qquad (5)$$

Or, in decimal form,

$$V_t = V_0\,(1 + 0.00366t). \qquad (6)$$

If t is below zero, we subtract the second term instead of adding it.

With this formula we may work exactly as with the formulas for the expansion of solids on page 11.

Example. Find the volume at 150°C of a gas measuring 10 cubic centimeters at 15°.

Solution. Applying formula 6 twice, we obtain

$$V_{150} = V_0\,(1 + 0.00366 \times 150) = 1.549\ V_0;$$

$$V_{15} = V_0\,(1 + 0.00366 \times 15) = 1.0549 V_0.$$

Therefore

$$V_{150} = V_{15}\,\frac{1.549}{1.0549} = 10 \times \frac{1.549}{1.0549} = 14.68 \text{ cub. cm., nearly.}$$

EXAMPLES FOR PRACTICE.

1. What will be the volume of 400 cubic inches of oxygen at 0°C, when heated to 30°?

Ans. 444 cubic inches, nearly.

2. If 160 cubic centimeters of hydrogen be measured at 50° C, what will be the volume of the gas at — 50°?

Ans. 110.45 cub. cm., nearly.

3. If 1,750 cubic feet of coal gas at 20°C are cooled to 0°, what will be the volume?

Ans. 1,630.6 cubic feet.

If the temperatures are expressed on the Fahrenheit scale, formula 6 becomes

$$V_{t'} = V_{32}\,[1 + 0.002035\,(t' - 32)], \qquad (7)$$

where t' is the temperature F.

EXAMPLES FOR PRACTICE.

1. 1,000 cubic feet of air are heated from 32° F to 90° F. What is the increase in volume?

Ans. 118 cub. ft.

2. 360 cubic feet of nitrogen at 70° F are cooled to 10° F. What is the volume after cooling?

Ans. 319.2 cub. ft.

When a quantity of gas confined in a given space is heated its pressure rises, and if the volume of the gas is kept constant the increase of pressure is very nearly the same as the above-described increase of volume at constant pressure. We may therefore deal with pressure changes due to temperature just as with changes of volume, employing formulas 6 and 7 as before.

EXAMPLE FOR PRACTICE.

A closed iron tank contains air at 50 lbs. pressure at 32° F. What will the pressure be if the temperature rises to 68° F, neglecting the effect of the expansion of the tank?

Ans. 53.66 lbs.

Since a reduction of temperature from 0° C to —1° C is accompanied by a loss of $\frac{1}{273}$ of the pressure of a gas, it would appear that by lowering the temperature to —273° C (= —459°* F) all the gas pressure would disappear, and the molecules would come completely to rest. But this means, from our definition of heat, the total absence of heat energy. This point, therefore, is called the **absolute zero** of temperature. Of course it can never be reached experimentally, but recent researches have carried the range of available temperatures far down toward it. By the evaporation of liquid and solid air and hydrogen, a temperature of —260°C has been attained.

Thus we see that to reduce ordinary temperatures to absolute temperature we add 273 if we are using Centigrade units, or 461 for Fahrenheit units.

LIQUEFACTION.

When heat is applied to an amorphous substance like glass or pitch, it changes gradually from a solid to a liquid, and there is no definite point at which melting occurs; but for most crystalline substances the change from solid to liquid is well marked. For such substances, melting (also called fusion) takes place according to the following laws:

1. Every substance melts at a certain temperature, which is always the same if the pressure on the substance is the same.
2. After fusion begins, the temperature of the mass remains at the melting point until the solid is completely melted.
3. In cooling, the substance solidifies at the temperature of melting.

TABLE OF MELTING POINTS.

	Centigrade.		Centigrade.
Ether,	—117°	Zinc,	418°
Mercury,	—39.4	Silver,	908
Ice,	0	Gold,	1072
Paraffin,	46	Copper,	1082
Wood's metal,	65 to 70	Cast iron.	1100 to 1200
Sulphur,	114	Wrought iron,	1600
Tin,	232	Platinum,	1775
Lead,	327	Iridium,	1950

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* NOTE. Some authorities quote —461° F.

Most substances increase in volume on melting, but some contract. The reverse change takes place on solidifying. Good castings can be made only from those metals or alloys which expand on solidifying, like cast iron and type-metal. Gold, aluminum, lead and silver must be stamped to get sharp impressions.

VAPORIZATION.

Since heat is the rapid, irregular vibratory motion of the molecules, it follows that if we add heat to a body we increase this motion. At a certain stage the vibration is so vigorous that the molecules (if the body is a solid) can no longer hold fast to one another, and the solid literally falls to pieces, that is, it melts. By applying more heat to the liquid and still further raising its temperature, we may finally reach a point at which some of the molecules are moving so violently as to escape into the air, altogether free from one another's influence. We then have a **vapor,** and the change into this aëriform condition is called **vaporization.**

If vaporization takes place slowly, and only at the surface of a liquid, it is called **evaporation.** Evaporation will be hastened by anything that facilitates the escape of molecules from the liquid surface, as by increasing the temperature of the liquid, lowering the pressure on it, or causing a breeze to play over the surface.

The fact that heat is due to molecular motion explains why evaporation is a cooling process. Naturally those molecules will escape first whose motion is most violent, that is, whose temperature is highest. The more sluggish (and therefore colder) molecules stay behind. Thus, as the liquid evaporates, the departing molecules take with them more than their proportionate share of heat, and the remaining liquid grows colder.

Cooling by evaporation may be illustrated by a simple experiment. Drop about a teaspoonful of water on a table or smooth board, and set a small tin dish on the water. Pour three or four tablespoonfuls of ether into the dish, and blow upon it with a pair of bellows. After two or three minutes of vigorous blowing, the dish will be found frozen fast to the board. (Caution.—*Keep ether away from lights.* Ether vapor is highly inflammable.)

When water is heated over a flame, the air (or any other gas) present is first driven off in tiny bubbles which rise to the surface and escape without noise. When the water nearest the flame is raised to the boiling point, bubbles of vapor are formed, which also rise through the water, but are condensed by the cooler layers before getting to the surface. This formation and condensation of steam bubbles produces the sound known as singing or simmering. The "water hammer" in steam pipes is of a somewhat similar nature but on a larger scale. When the entire mass is heated to the boiling point, the steam bubbles rise to the surface and break, discharging their contents into the air with a characteristic noise. This stage is called **ebullition** or boiling.

Like air, steam is colorless, transparent and invisible. What is commonly called "a cloud of steam" is really a cloud of fine water particles condensed from steam. Observe any steam jet, and notice that at the end of the pipe nothing whatever can be seen, the jet becoming visible only after it has gone far enough from the pipe to be cooled and condensed.

The increase of volume by vaporization is usually very great. For example, a cubic inch of water will make 1,661 cubic inches of steam at atmospheric pressure.

By increasing the pressure on the surface of a boiling liquid, we make it more difficult for the molecules to escape; they cannot escape unless given more motion, that is, unless they have a higher temperature than before. In other words, an increase of pressure raises the boiling point. The following table gives the boiling point of water under different pressures, as measured by a steam gage:

BOILING POINT OF WATER.

GAGE PRESSURE.	TEMPERATURE, FAHR.
0 (atmosphere)	212°
50 lbs.	297.4
100 "	337.6
150 "	365.7
200 "	387.8

The laws of vaporization are similar to the laws of fusion given on page 15. The following table gives the boiling points in degrees Centigrade of some liquids, under a pressure of one atmosphere:

BOILING POINTS.

Liquid air,	— 188°	**Chloroform,**	**61.2°**
Ammonia,	— 38.5	**Alcohol,**	**78.4**
Sulphurous anhydride,	— 10.1	**Mercury,**	**357.**
Ether,	34.9	**Sulphur,**	**444.5**

DISTILLATION.

The difference in the boiling points of substances has an important application in the arts, in the separation of liquids from solids, or of liquids from each other. The simple removal of a liquid from a solid, as in evaporating brine to recover the salt, needs no special appliances; but when the evaporated liquid is to be saved, an apparatus called a **still** is used, and the process is called **distillation.**

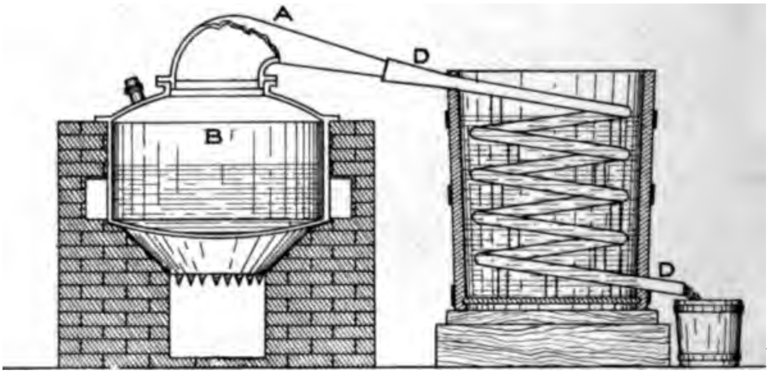
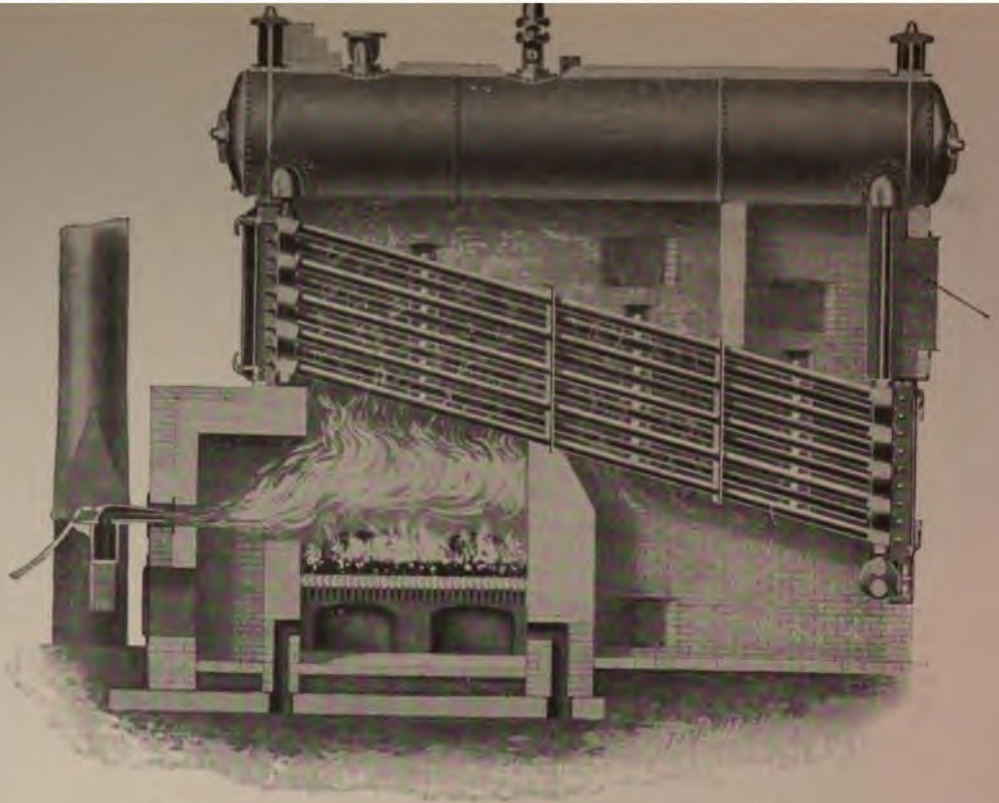


Fig. 5.

A still consists essentially of two parts: a *retort* in which the liquid is vaporized, and a *condenser* in which it is reduced to liquid again. Fig. 5 shows a form of the apparatus for separating a liquid from a solid, or one liquid from another of different boiling point, such as alcohol and water. The mixture is poured into the retort B, and then heated to about 90° C, which is above the boiling point of alcohol but below that of water. The vaporized alcohol escapes through A to the *worm* D. This is a simple



Section of Babcock and Wilcox Boilers Fitted with Kennedy Burners for Burning Blast Furnace Gas.

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helical coil of pipe surrounded by cold water, and serving to condense the vapor, which runs out as a liquid at the bottom. The cooling water is constantly changed by supplying fresh cold water at the bottom and drawing off the heated water from the top.

This process is called **fractional distillation,** and is carried out on an enormous scale in the refining of petroleum. When the distillate is to be very pure, it is necessary to repeat the operation one or more times. When practicable, especially with inflammable liquids, the heating is done by steam pipes supplied from a distant boiler.

THE MEASUREMENT OF HEAT. Heat Units.

There are two units of measurement for determining quantities of heat. The **British thermal unit** (often abbreviated B. T. U.) is the amount of heat required to raise one pound of water from 59° to 60° Fahrenheit. The French unit, or **calorie,** is the amount of heat required to raise the temperature of one gram of water from 15° to 16° Centigrade. The former is much used in engineering calculations involving steam and fuels, and the latter in all other scientific work.

LATENT HEAT.

If we put a block of very cold ice into a vessel over a flame and insert a thermometer into the ice, we shall observe the thermometer rise to 0° C, at which point the ice begins to melt. The temperature of the ice and water then shows no further change until all the ice has melted, though the heat is applied continuously. Only after the melting is complete will the temperature of the water begin to rise. It will then increase until 100° C is reached, when ebullition begins, the temperature not rising above 100° until all the water has boiled away.

We thus see that in changing from ice to water and from water to steam there is absorbed a considerable quantity of heat which does not show on the thermometer. The quantities of heat absorbed in the processes of fusion and vaporization are called the *latent heat of fusion* and the *latent heat of vaporization* respectively.

The following example shows how the latent heat of fusion of ice may be measured. If we mix a gram of water at 80° C with a gram at 0°, we get, as we should expect, two grams at 40°. But if we mix a gram of water at 80° with a gram of ice at 0°, we get two grams of water as before, but the temperature is 0° instead of 40°. The heat which in the first case raised the temperature of the water has in the second case been needed merely to melt the ice. The calculation of the latent heat is made in the following way:

One gram of water falling through 80 degrees of temperature will give out 1 × 80, or 80 calories. This quantity of heat is required to change one gram of ice at 0° into water at 0°. Therefore the latent heat of fusion of ice is 80; in other words, the heat which will just melt a quantity of ice will raise 80 times as much water one degree C.

By a somewhat simiiar method it is found that the latent heat of vaporization of water at atmospheric pressure is 536.5. That is, to evaporate one gram of water (already at the boiling point) will require as much heat as would raise the temperature of 536.5 grams one degree, or 5.365 grams from freezing to boiling (0° to 100° C).

Expressed in terms of the Fahrenheit degree and the British thermal unit, the latent heats of fusion and vaporization are 144 and 966 respectively.

The large values of these quantities are of the greatest importance both in nature and in the arts. The great amount of heat necessary to melt the ice of winter makes the melting a slow process, and lessens the danger of destructive floods in the spring. In the autumn the water in freezing gives out again the heat absorbed in melting, and the transition to winter is thus rendered less abrupt.

Since a pound of steam in condensing will give out as much heat as 53.65 pounds of water cooling from 100° C to 90° C, or from 90° to 80°, it follows that steam pipes for heating may be made smaller than water pipes for the same service. It also shows the value of steam as a carrier of heat; and in the arts advantage of this is taken in innumerable ways. (See also page 19).

SPECIFIC HEAT.

When equal quantities of different substances are raised equally in temperature, different amounts of heat are required; and in cooling through equal temperature intervals different substances give out different amounts of heat.

For example, if we mix a pound of water at 80° C with a pound at 0° C, we get two pounds at 40°; but if we pour a pound of lead shot at 80° into a pound of water at 0°, the resulting temperature will be only 2.3°. A pound of lead, therefore, falling through 77.7 degrees of temperature, is able to raise a pound of water only 2.3 degrees. The fall of temperature of the hot body is nearly twice as great as in the first case, and the heat given out in the fall only about one-seventeenth as much. The heat capacity of the lead is therefore much less than that of the water.

If we know how much heat will raise the temperature of a given substance a certain amount, and how much is required to raise the temperature of an equal quantity of water by the same amount, then the ratio of these two quantities is called the specific heat of the substance. In other words, if we take the specific heat of water as our standard (as we practically do in defining the units of heat), the specific heat of a substance is expressed by the number of heat units required to raise the unit quantity of the substance one degree in temperature.

One of the simplest methods of determining specific heat is by mixing the substance with water. Suppose that 6 pounds of mercury at 100°C are poured into 2 pounds of water at 0°C, and that the resulting temperature of the "mixture" is 9°. The specific heat S of the mercury can then be found as follows:

In falling from 100° to 9° the 6 pounds of mercury give out $6 \times (100 - 9) \times S$, or 546 S heat units. These have gone to heat 2 pounds of water from 0° to 9°, which requires 2×9, or 18 heat units. Hence we may write

$$546\ S = 18$$

Therefore

$$S = 0.033.$$

EXAMPLE FOR PRACTICE.

Half a pound of a metal at 212° F is dropped into one pound of water at 68° F. The temperature of the mixture is then observed to be 76° F. What is the specific heat of the metal?

Ans. 0.117.

TABLE OF SPECIFIC HEATS.

Hydrogen,	3.4090	Wrought iron,	0.1124
Alcohol,	0.602		
Ammonia (gas),	0.5084	Copper,	.0949
Ice,	.5040		
Air,	.2375	Zinc,	.0935
Aluminum,	.2122	Tin,	.0562
Glass,	.193 to .198	Mercury,	.0330
Cast iron,	.1298	Lead,	.0314
Steel,	.1181		

With the foregoing principles and the help of suitable tables, many problems can be solved. For example, let us find how many calories will be required to convert 10 grams of ice at — 12° C into steam at 100° C.

Solution. Required to raise the ice from — 12° to 0°,

$$10 \times 12 \times 0.504 = 60.48 \text{ calories.}$$

Required to melt the ice,

$$10 \times 80 = 800 \text{ calories.}$$

Required to raise the water from 0° to 100°,

$$10 \times 100 = 1{,}000 \text{ calories.}$$

Required to vaporize the water,

$$10 \times 536.5 = 5{,}365 \text{ calories.}$$

Total number of calories required,

$$60.48 + 800 + 1{,}000 + 5{,}365 = 7{,}225.5 \text{ (nearly).}$$

EXAMPLES FOR PRACTICE.

1. What weight of water at 75° C will just melt 15 pounds of ice at 0°?

Ans. 16 pounds.

2. One kilogram of water at 40°, 2 kilograms at 30°, 3 kilograms at 20°, and 4 kilograms at 10° are mixed. Find the temperature of the mixture.

Ans. 20°.

3. How many heat units will be required to melt 5 grams of ice at —20° C? How many grams of water at 50° C would do it?

Ans. 450.4 heat units; 9.01 grams.

If we wish to use Fahrenheit degrees and British thermal units in our calculations, it is necessary to remember that the numbers representing the heats of fusion and of vaporization are different, but that the specific heat, which is a mere ratio, is the same in both systems.

For example, let us find how many B. T. U. are required to convert 12 lbs. of ice at 10° F into steam at 212° F.

Solution. Required to raise the ice from 10° F to 32° F,

$$12 \times 22 \times 0.504 = 133.056 \text{ B. T. U.}$$

Required to melt the ice,

$$12 \times 144 = 1{,}728 \text{ B. T. U.}$$

Required to raise the water from 32° to 212°,

$$12 \times 180 = 2{,}160 \text{ B. T. U.}$$

Required to vaporize the water,

$$12 \times 966 = 11{,}592 \text{ B. T. U.}$$

Total number of B. T. U. required,

$$133.056 + 1{,}728 + 2{,}160 + 11{,}592 = 15613 \text{ (approx.).}$$

EXAMPLE FOR PRACTICE.

How many B. T. U. are required to convert 10 lbs. of ice at 15° F into steam at 212° F?

Ans. 12,985 B. T. U.

For ordinary purposes we may proceed as above; but as the specific heat and latent heat of water vary for different temperatures, we must, where great accuracy is necessary, employ a table of the properties of steam and water.

THE PROPERTIES OF STEAM.

The relation between the external pressure and the boiling point of water is a perfectly definite one, but cannot be exactly expressed by any mathematical equation. In dealing with this and other properties of steam and water, it is therefore customary to refer to suitable tables where the values are given, as determined by experiment. Such tables are called **steam tables**, and are much used in engineering calculations.

In the following table are given (1) the pressure above absolute vacuum, (2) the corresponding temperature, (3) the amount of heat in B. T. U. required to raise a pound of water from 32° F to the given temperature, (4) the amount of heat in B. T. U. required to vaporize a pound of water at the given temperature; (5) equals the sum of (3) and (4).

A steam gage measures pressures above the atmospheric pressure; hence, when readings are taken from a steam gage, the barometric pressure (averaging 14.7 lbs. per sq. in., or in round numbers 15 lbs.) must be added to obtain the "absolute" pressure.

With a steam table we can extend considerably the range of problems like those on page 23. For example, let us find how many pounds of steam at 65 lbs. gage pressure will be needed to raise the temperature of 60 pounds of water from 50° F to 100° F.

Solution. To raise one pound of water from 50° to 100° requires 50 B. T. U.; and for 60 pounds we need 50 × 60, or 3,000 B. T. U. At 65 lbs. gage pressure (80 lbs. absolute) the total heat of one pound of steam is 1,177 B. T. U., and this amount would all be available if we cooled it down to 32° F. But since the cooling is not carried below 100° F, we cannot use 100—32,

TABLE OF PROPERTIES OF SATURATED STEAM.

Pressure in pounds per sq.in. above vacuum.	Temperature in degrees Fahrenheit.	Heat in liquid from 32° in units.	Heat of vaporization, or latent heat in heat units	Total heat in heat units from water at 32°.	Density or weight of cubic ft. in pounds.	Volume of 1 pound in cubic feet.	Total pressure above vacuum.
1	101.99	70.0	1043.0	1113.1	0.00299	334.5	1
2	126.27	94.4	1026.1	1120.5	0.00576	173.6	2
3	141.62	109.8	1015.3	1125.1	0.00844	118.5	3
4	153.09	121.4	1007.2	1128.6	0.01107	90.31	4
5	162.34	130.7	1000.8	1131.5	0.01366	73.21	5
6	170.14	138.6	995.2	1133.8	0.01622	61.67	6
7	176.90	145.4	990.5	1135.9	0.01874	53.37	7
8	182.92	151.5	986.2	1137.7	0.02125	47.06	8
9	188.33	156.9	982.5	1139.4	0.02374	42.12	9
10	193.25	161.9	979.0	1140.9	0.02621	38.15	10
14.7	212.00	180.9	965.7	1146.6	0.03794	26.36	14.7
15	213.03	181.8	965.1	1146.9	0.03826	26.14	15
20	227.95	196.9	954.6	1151.5	0.05023	19.91	20
25	240.04	209.1	946.0	1155.1	0.06199	16.13	25
30	250.27	219.4	938.9	1158.3	0.07360	13.59	30
35	259.19	228.4	932.6	1161.0	0.08508	11.75	35
40	267.13	236.4	927.0	1163.4	0.09644	10.37	40
45	274.29	243.6	922.0	1165.6	0.1077	9.287	45
50	280.85	250.2	917.4	1167.6	0.1188	8.414	50
55	286.89	256.3	913.1	1169.4	0.1290	7.696	55
60	292.51	261.9	909.3	1171.2	0.1409	7.097	60
65	297.77	267.2	905.5	1172.7	0.1519	6.583	65
70	302.71	272.2	902.1	1174.3	0.1628	6.143	70
75	307.38	276.9	898.8	1175.7	0.1736	5.762	75
80	511.80	281.4	895.6	1177.0	0.1843	5.426	80
85	316.02	285.8	892.5	1178.3	0.1951	5.126	85
90	320.04	290.0	889.6	1179.6	0.2058	4.859	90
95	323.89	294.0	886.7	1180.7	0.2165	4.619	95
100	327.58	297.9	884.0	1181.9	0.2271	4.403	100
105	331.13	301.6	881.3	1182.9	0.2378	4.205	105
110	334.56	305.2	878.8	1184.0	0.2484	4.026	110
115	337.86	308.7	876.3	1185.0	0.2589	3.862	115
120	341.05	312.0	874.0	1186.0	0.2695	3.711	120
125	344.13	315.2	871.7	1186.9	0.2800	3.571	125
130	347.12	318.4	869.4	1187.8	0.2904	3.444	130
140	352.85	324.4	865.1	1189.5	0.3113	3.212	140
150	358.26	330.0	861.2	1191.2	0.3321	3.011	150
160	363.40	335.4	857.4	1192.8	0.3530	2.833	160
170	368.29	340.5	853.8	1194.3	0.3737	2.676	170
180	372.97	315.4	850.3	1195.7	0.3945	2.535	180
190	377.44	350.1	847.0	1197.1	0.4153	2.408	190
200	381.73	354.6	843.8	1198.4	0.4359	2.294	200
225	391.79	365.1	836.3	1201.4	0.4876	2.051	225
250	400.99	374.7	829.5	1204.2	0.5393	1.854	250
275	409.50	383.6	823.2	1206.8	0.5913	1.691	275
300	417.42	391.9	817.4	1209.3	0.644	1.553	300
325	424.82	399.6	811.9	1211.5	0.696	1.437	325
350	431.90	406.9	806.8	1213.7	0.748	1.337	350
375	438.40	414.2	801.5	1215.7	0.800	1.250	375
400	445.15	421.4	796.3	1217.7	0.853	1.172	400
500	466.57	444.3	779.9	1224.2	1.065	.939	500

or 68 B. T. U., and the amount available is therefore 1,177 — 68 = 1,109 B. T. U.

The quantity of steam therefore needed is

$$\frac{3{,}000}{1{,}109} = 2.705 + \text{pounds.}$$

Ans. 2.705 + pounds.

The small quantity of steam in this example well illustrates the great heating power of steam.

EXAMPLES FOR PRACTICE.

1. How many pounds of steam at 100 lbs. absolute pressure will raise 250 pounds of water from 50° F to 150° F?

Ans. 23.5 pounds.

2. How many pounds of steam at 35 pounds gage pressure will just melt 1,000 pounds of snow at 32° F?

Ans. 123.3 pounds.

It will be seen that the values of the total heat column in the table increase but slowly, while the pressure and temperature increase rapidly. A pound of high-pressure steam thus contains but little more heat than a pound of low-pressure steam, and consequently requires but little more fuel to produce it. Since high-pressure steam is more effective in steam engines, there is therefore a decided thermodynamic advantage in using steam of the highest practicable pressure.

Superheated Steam. From the table we see that there is a perfectly definite temperature for steam at any given pressure. Steam or other vapors in this condition are said to be **saturated,** for if the temperature is lowered some of the vapor will condense immediately into liquid. If, however, we pass steam through a separately heated pipe or chamber it is easily possible to raise its temperature by any desired amount above the given values. Steam in this condition is called **superheated.** For steam engines it has certain advantages over saturated steam, which are discussed in the Instruction Papers on the Steam Engine.

TRANSFER OF HEAT.

Heat may be transferred from one body to another by conduction, convection or radiation.

Conduction. When one end of a metal bar is heated in the fire the other end gradually becomes warmer. The heated molecules communicate their motion to their immediate neighbors; and the heat thus travels along the bar, and may be removed by a cold body at the distant end. This process is called conduction. In this way the heat of a boiler furnace is communicated to the water in the boiler.

A brass pin held in a gas flame will burn the fingers almost instantly, while a bit of glass may be melted at one end before the other becomes hot, and a match may be burned to the finger-tips without discomfort. It is thus clear that substances differ greatly in conductivity. There are great differences even among metals; a copper rod will conduct heat much more rapidly than an iron rod.

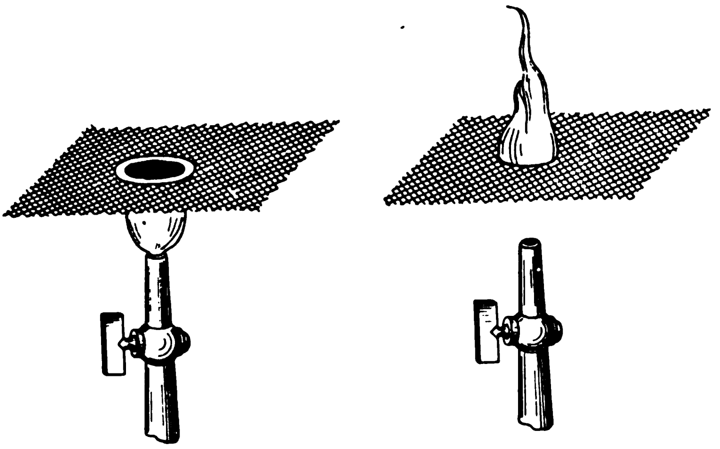

Fig. 6.

If a piece of wire gauze is held over an unlighted gas jet, the gas may be lighted on either side (Fig. 6), but the flame will not pass through the meshes. The wires conduct the heat away so rapidly that the gas on the other side does not get hot enough to ignite. This is the principle of the safety lamp, used in coal mines where inflammable gases collect. The lamp flame is surrounded by a wire gauze, and thus kept from igniting the dangerous gases outside.

The following table gives the relative conductivity of several substances. The table well shows the great value of a layer of snow as a protective blanket on the earth:

RELATIVE THERMAL CONDUCTIVITIES.

Silver,	100	Lead,	7
Copper,	66 to 74	Marble,	0.0074
Brass,	18 to 23	Ice,	0.0052
Iron,	15	Snow,	0.00046

Convection. Excepting mercury, liquids and gases are poor conductors of heat; but when such bodies are heated from below, the heated portion expands and rises through the mass, and is replaced below by a colder portion, which is heated and rises in its turn. In this way what are called **convection currents** arise, and the heat is distributed throughout the fluid by actual motion within the mass itself. The heating of houses by hot water is an application of this principle.

Convection also takes place in gases; the winds of the atmosphere illustrate it on a large scale.

Radiation. We have seen that the molecules of a hot body are in very rapid vibration. Some of the energy of this vibration is communicated in the form of waves to the space surrounding the body. If the motion happens to lie within certain limits, the waves affect our eyes and we call them light-waves. But all such waves, visible or otherwise, represent energy which is sent out by the hot body. When they fall upon any other body, they are either reflected or absorbed and transformed into heat. Polished silver reflects over 90 per cent of the waves falling on it; charcoal absorbs nearly all, and hence rises in temperature when exposed to the radiations of a hot body.

Energy in this form is called radiant energy. By it the heat of the sun is transmitted to the earth. Since it is in the form of ether-waves, many of the experiments ordinarily performed with light-waves may be repeated with the radiations from a hot body, whether visible or not. The common burning-glass shows the result of bringing such rays to a focus by refraction. If a pair of concave mirrors be set facing each other, as shown in Fig. 7, and a source of heat be placed in the focus of one, a thermometer in the focus of the other will quickly show a rise in temperature though the mirrors are many feet apart.

It does not follow, however, that bodies transparent to light are equally transparent to other radiations. Glass, for example, is quite opaque to the invisible radiations that are most effective in producing heat. Also, a solution of alum in water will cut off most of these radiations, while allowing the light-waves to pass freely; and a glass tank of alum water is often used in stereopticons to keep the heat of the lamp from the rest of the apparatus.

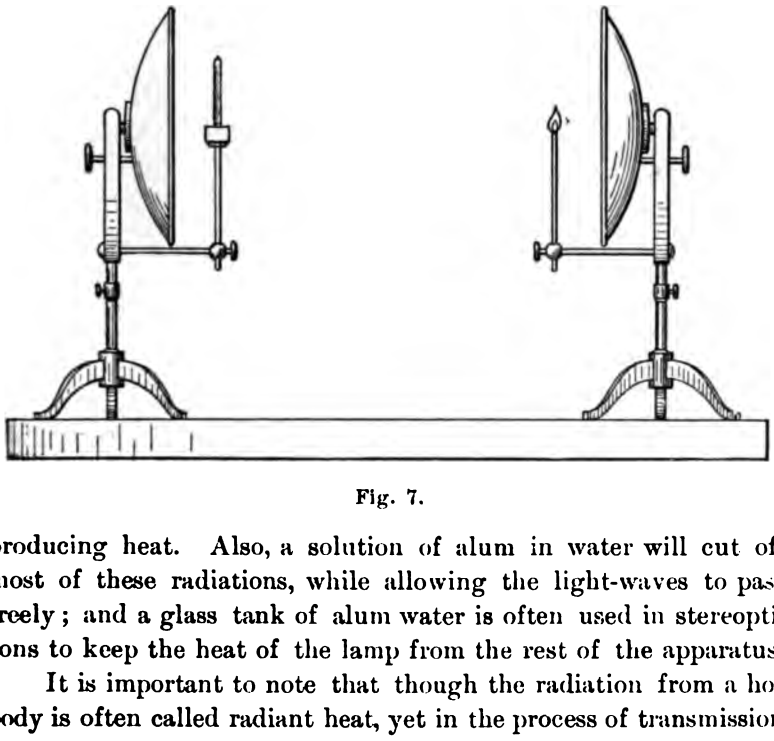

Fig. 7.

It is important to note that though the radiation from a hot body is often called radiant heat, yet in the process of transmission it is not heat at all, but a wave motion in the ether, which is energy of a very different kind. A somewhat analogous case is present in the incandescent lamp; the heat which appears at the lamp does not come along the wires as heat, but as electrical energy, which is altogether different. It is indeed transformed into heat in the lamp, but is not itself heat. In like manner, radiant energy is transformed into heat only by falling on some body which absorbs it. It is thus possible to make a good burning-glass by shaping a piece of clear ice into the form of a lens, a thing which would clearly be impossible if the energy passing through the ice lens were in the form of heat.

THERMODYNAMICS.

This is the science which deals with the relations between heat and mechanical energy. It rests on two fundamental propositions called the first and second laws of thermodynamics.

The **first law** states that when heat is transformed into mechanical energy, or the reverse, the quantity of heat is always exactly equivalent to the quantity of mechanical energy.

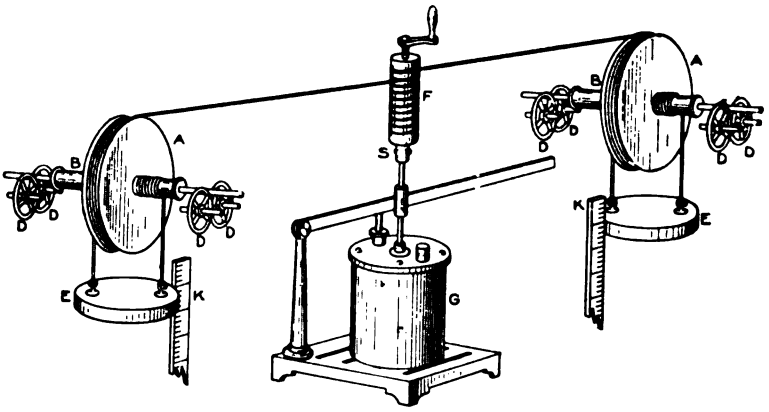

Fig. 8.

The production of heat by friction is familiar to every one; but it is not so clear that there is an exact equivalence between the energy lost by friction and the heat produced. Joule was the first to establish the relation accurately. The principle of his apparatus is shown in Fig. 8. The falling weights EE turned a paddle-wheel stirrer inside the cylindrical vessel G, which was filled with water and was much like the common ice-cream freezer. The friction of the stirrer heated the water; and when the distance was measured through which the weights fell, it was possible to calculate the relation between the work done by the falling weights and the heat developed in the water.

Later experiments on a larger scale have given results which are more accurate than was possible with this apparatus. The values now accepted are the following:

427.3 kilogrammeters of work or energy are required to raise the temperature of one kilogram of water from 15° to 16° C at sea-level, in latitude 45°.

In English units, 778.8 foot-pounds of work are required to raise the temperature of one pound of water from 59° to 60° Fahrenheit at sea-level, in latitude 45°.

These values vary slightly for different places, because the weight of a pound depends on the pull of gravity, and this varies in different places; but for most engineering purposes 779 foot-pounds would be near enough.

This law states in effect that we cannot get energy for nothing. Whenever we get work from heat, a definite quantity of heat disappears; and whenever we convert mechanical energy into heat, we must expend 779 foot-pounds for every British thermal unit produced.

The **second law** of thermodynamics asserts that heat cannot of itself pass from a cold to a hot body. Since a hot body in cooling gives out heat which, in part at least, may be converted into work, it might seem that by cooling it indefinitely we could get an infinite amount of work from it. But the second law declares that the process stops as soon as the hot body has cooled to the temperature of its surroundings; and if we wish to cool it further we must expend energy in so doing. It follows from this that no heat engine can convert into work all the heat which it receives. As soon as the steam (or other working fluid) has fallen to the temperature of the exhaust, the remaining heat in it is no longer available for doing useful work. If the heat is supplied at the absolute temperature T_1 and the exhaust is at the temperature T_2, the efficiency of the engine cannot be greater than $\frac{T_1 - T_2}{T_1}$, no matter what is used as the working fluid of the engine.

THERMODYNAMICS OF PERFECT GASES.

The subject of thermodynamics cannot be fully treated by elementary methods of analysis; in the following brief discussion, however, no advanced methods are used.

The thermodynamics of steam will be more readily understood by first taking up the simpler case of a perfect gas. Air, oxygen, nitrogen, hydrogen and some others, behave very nearly as perfect gases; others, as ammonia, carbon dioxide and sulphur dioxide, do not.

Boyle's Law. The product of the pressure P and the volume V of a perfect gas is constant if the temperature is constant; that is, if at a pressure P_1 a body of gas has the volume V_1, and at some other pressure P_2 has the volume V_2, then

$$P_1V_1 = P_2V_2 = \text{constant}.$$

Example. If 12 cubic feet of air at 135 pounds absolute pressure expand to 27 cubic feet at the same temperature, what will be the pressure? What pressure would a gage indicate?

Solution. $P_{135}V_{135} = P_{27}V_{27}$

$$135 \times 12 = P_{27} \times 27$$

Therefore $P_{27} = 60$ pounds, absolute.
Gage pressure = absolute pressure — atmospheric pressure.

$$P_{gage} = 60 - 14.7 = 45.3 \text{ pounds. Ans.}$$

EXAMPLE FOR PRACTICE.

Ten cubic feet of air at 2.3 lbs. gage are compressed until the gage pressure is 7.3 lbs. Find the volume.

Ans. 7.727 cub. ft.

Since one pound of air at 32° F occupies 12.387 cubic feet, we may calculate the product PV of a pound of air as follows:

$$V = 12.387$$

$$P = 14.7 \times 144 = 2{,}117 \text{ (nearly)}.$$

Hence $PV = 2{,}117 \times 12.387 = 26{,}223$.

Law of Boyle and Charles. For a perfect gas the product PV is proportional to the absolute temperature T. In the form of an equation, this becomes $\frac{PV}{T} = \text{constant}$, or $PV = \text{constant} \times T$.

This is usually written $PV = RT$. For air we may easily calculate R as follows: We have just seen that at 32° F, $PV = 26{,}223$, and $T = 32 + 461$, or 493° absolute temperature. Therefore,

$$\frac{26{,}223}{493} = R = 53.2.$$

Example. What volume will be occupied by a pound of air at 50° F and 40 pounds pressure (absolute) per sq. in.?

Solution. $P = 40 \times 144 = 5{,}760$ lbs. per sq. ft.

$$T = 50 + 461 = 511° \text{ absolute temperature.}$$

Therefore $$5{,}760 \times V = 53.2 \times 511.$$

$$V = \frac{53.2 \times 511}{5{,}760}.$$

$$V = 4.72 \text{ cub. ft. (nearly).}$$

Example. A quantity of air at 75 lbs. gage pressure and 60° F is heated to 90° F. What is the pressure?

Solution. Since the volume is unaltered, the pressure is proportional to the absolute temperature. We have

$$60° F = 60 + 461 = 521° \text{ absolute.}$$

$$90° F = 90 + 461 = 551° \text{ absolute}$$

Therefore $$P_1 : P_2 :: T_1 : T_2.$$

$$P_2 = \frac{T_2}{T_1} \times P_1.$$

$$P_2 = \frac{551}{521} \times (75 + 14.7) = 94.86 \text{ lbs.} \quad \text{Ans.}$$

EXAMPLES FOR PRACTICE.

1. What is the weight of 6 cubic feet of air at 60° F and 25 pounds absolute pressure per square inch?

Ans. .78 lbs.

SUGGESTION. First find the volume of one pound under the given conditions.

2. A reservoir containing 4 cubic feet of air at a temperature of 40° F and a pressure of 100 pounds per square inch abs., is heated to 80° F. What will the pressure be, and how much does the air weigh?

Ans. $\begin{cases} 107.98+\text{lbs.} \\ 2.16+\text{lbs.} \end{cases}$

Isothermal and Adiabatic Expansion. When a gas expands and does work, as by pushing a piston in a cylinder, we see from the first law of thermodynamics that the equivalent in the form of heat must be supplied from somewhere. If the temperature of the gas is to be kept constant, heat must be supplied to it from the outside, in exact equivalent to the work done. In such cases the expansion is said to be **isothermal**, and the relation between pressure and volume is as shown by the dotted curve I of Fig. 9. This curve is an equilateral hyperbola. But if no heat be allowed to enter the gas, as would be the case if the cylinder and piston were perfect non-conductors of heat, the work done in expansion will be at the expense of the heat energy in the gas itself, and its temperature will therefore fall during the expansion. We have seen that the pressure is less as the temperature falls, other things being equal; hence under the conditions the pressure will fall faster than if the temperature were kept up by the addition of heat from outside. This is shown by the curve A of Fig. 9. Curves of this kind, representing expansion or compression without communication of heat to or from the gas, are called **adiabatics.** It is evident that adiabatic expansion along A from v_2 to v_1 is accompanied by a greater fall of pressure than isothermal expansion along I.

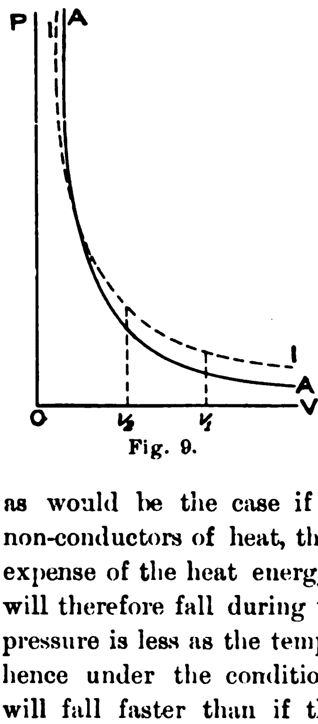

Fig. 9.

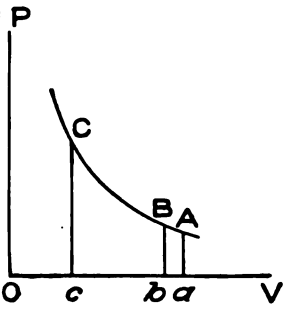

Fig. 10.

Both isothermal and adiabatic curves are of great importance

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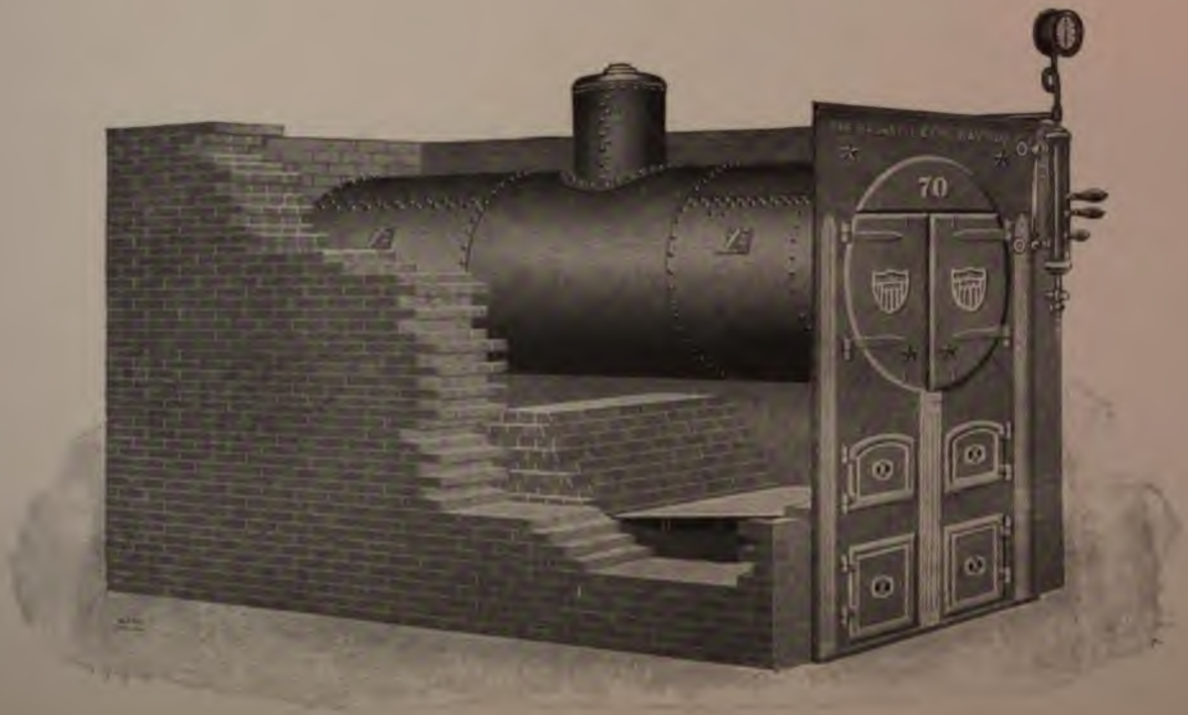

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in thermodynamic studies, but they represent conditions that are only imperfectly realized in practice. The general expression for an adiabatic curve is PV^n = constant. For air, $n = 1.405$. Most problems involving adiabatic and isothermal curves cannot be solved without the aid of higher mathematical processes than are used in this Paper.

Work Done in Expansion. Suppose we have a piston whose

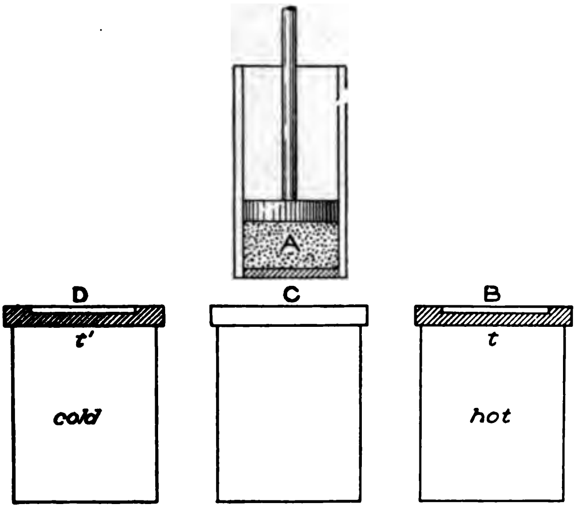

Fig. 11.

area is A square inches, which is acted upon by a pressure of p pounds per square inch, and which moves through a distance of m feet in consequence. Then the total pressure is pA pounds, and the work done is $pA \times m$ foot-pounds. But $A \times m$ is the volume of the cylinder swept out by the piston in its stroke; and calling this V, we have:

$$\text{Work done} = \text{pressure} \times \text{volume} = PV.$$

This can be conveniently shown on the pressure-volume diagram. Suppose B (Fig. 10) represents the pressure and volume of a gas, which then expands a little to the condition A. Then the average pressure during the expansion will be $\frac{1}{2}(Bb + Aa)$, and the work done will be $\frac{1}{2}(Bb + Aa) \times ab$ = the area $BAab$.

Since we may regard the whole change from C to A as made up of portions like that from B to A, it follows that in changing from C to A along the path CBA the expanding gas will do the work represented by the area CA*ac*.

The Carnot Cycle. This principle can be applied to the operation of heat engines. Let the working substance of a heat engine be a gas A, enclosed in a cylinder (Fig. 11) with nonconducting walls and piston and a perfectly conducting bottom. Let B be a hot body kept at the temperature t, and D a cold one kept at the temperature t'; and let C be a nonconducting stand. Then we may imagine the gas to undergo the following cycle of operations :

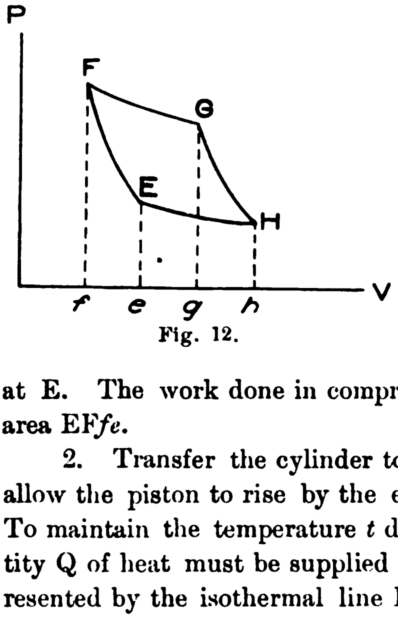

Fig. 12.

1. Set the cylinder on the stand C, with the gas at the temperature t', and compress the gas adiabatically until its temperature rises to t. On the pressure-volume diagram (Fig. 12), this stage will be represented by the line EF, starting at E. The work done in compressing will be represented by the area EF*fe*.

2. Transfer the cylinder to the hot body B (Fig. 11), and allow the piston to rise by the expansion of the compressed gas. To maintain the temperature t during expansion, a certain quantity Q of heat must be supplied from B. This stage will be represented by the isothermal line FG (Fig. 12), and the work done by the expanding gas by the area FG*gf*.

3. Set the cylinder on the stand C (Fig. 11), and allow the gas to expand still further, until it cools to the temperature t'. This change is shown by the adiabatic line GH (Fig. 12), and the work done in the expansion by the area GH*hg*.

4. Place the cylinder on D and push the piston down to its first position. The heat Q′ developed by the compression will be removed by the cold body D, and the temperature of the gas will remain unchanged. The change is shown by the isothermal line HE (Fig. 12), and the work done on the gas by the area HE*eh*.

The gas has now reached its initial condition. It has done an amount of work represented by the area FGH*hf*, and has had done on it the work represented by HEF*fh*. The difference EFGH is the net work done in the cycle; and to do it, it has been necessary to take a quantity of heat Q from the hot body, and to discharge a quantity Q′ into the cold body. The efficiency of the operation is

$$\frac{\text{Heat utilized}}{\text{Heat received}} = \frac{Q - Q'}{Q}.$$

The above cycle of operations is called the Carnot cycle, because Carnot first applied it as a method of reasoning. The efficiency of a steam engine working on the above cycle can be shown as follows:

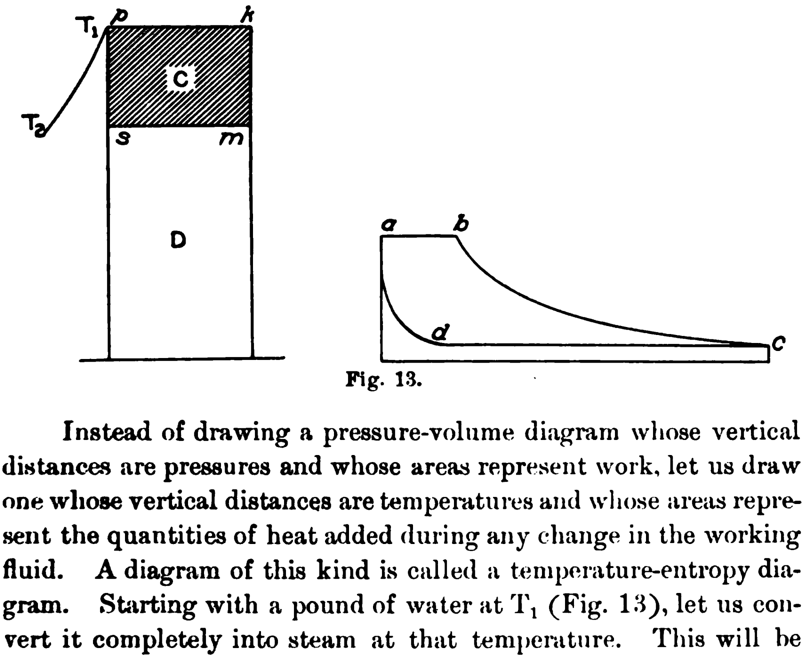

Fig. 13.

Instead of drawing a pressure-volume diagram whose vertical distances are pressures and whose areas represent work, let us draw one whose vertical distances are temperatures and whose areas represent the quantities of heat added during any change in the working fluid. A diagram of this kind is called a temperature-entropy diagram. Starting with a pound of water at T_1 (Fig. 13), let us convert it completely into steam at that temperature. This will be represented in our diagram by the line *pk*, and the heat added to produce the change will be shown by the areas C + D. Then let the steam expand adiabatically until it reaches the temperature T_2. This is represented by the line *km*, which is vertical and represents no additional area, because no heat is added to or withdrawn from the steam from outside. Suppose, during the return stroke of the piston, the steam is cooled within the cylinder itself, until it arrives at the point *s*. In this operation we shall reject from the cylinder a quantity of heat represented by the area D. Finally, let us compress adiabatically the mixture of steam and water in the cylinder until we have once more a pound of water at the higher temperature T_1. This gives the line *sp*, ending where the cycle began.

We have thus supplied during the cycle the heat represented by the areas C + D, and the heat rejected is represented by D. Therefore the efficiency is $\frac{C}{C + D}$, and from the diagram it will be seen that this is equal to $\frac{T_1 - T_2}{T_1}$.

In the actual engine the last step is very imperfectly performed, because only a small amount of steam remaining in the cylinder is compressed; the remainder, exhausted from the cylinder at the lower temperature T_2, must be heated to the temperature T_1 by heat from the boiler, or replaced by an equal amount thus heated.

We thus have the important conclusion that the efficiency of a steam engine depends entirely on the ratio of the temperatures between which it operates; it follows that the efficiency is always small. For example, suppose an engine takes steam at 300° F and exhausts at 212° F. Its efficiency cannot be greater than

$$\frac{(300 + 461) - (212 + 461)}{(300 + 461)} = 11.3 \text{ per cent.}$$

EXAMPLE FOR PRACTICE.

Using the steam table on page 25, find the maximum possible efficiency of an engine taking steam at 150 lbs. absolute pressure and exhausting at 5 lbs. absolute pressure.

Ans. 23.9 per cent.

THE STEAM ENGINE.

Without entering into a detailed description of the mechanism, it will be sufficient here to say that in the steam engine, steam is admitted under pressure from a boiler into a metal cylinder behind a piston, as represented in Fig. 14. Its pressure drives the piston forward, doing useful work. When the piston has moved through a part of its stroke the steam supply is cut off, and the stroke is completed by the expansion of the steam confined in the cylinder. By the first law of thermodynamics this expansion cools the steam, since work is done in the process; but the expansion is not adiabatic, since the cylinder and piston give up some heat to the steam within. At the end of the stroke the exhaust valve opens and the cooled steam escapes into the atmosphere or condenser through the exhaust pipe A. The operation is then repeated on the other side of the piston.

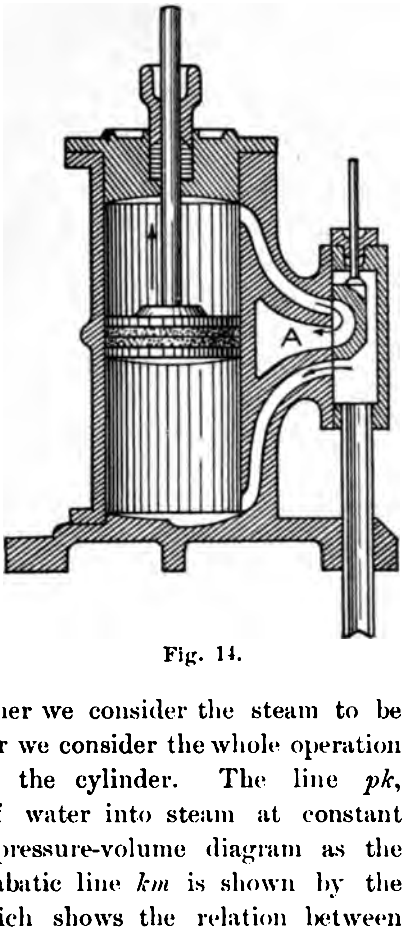

Fig. 14.

The pressure-volume diagram in Fig. 13 shows the process graphically, and can be instructively compared with the temperature-entropy diagram of the same figure. For purposes of analysis it is immaterial whether we consider the steam to be supplied from outside, or whether we consider the whole operation of heating to take place inside the cylinder. The line *pk*, representing the conversion of water into steam at constant pressure, will appear on the pressure-volume diagram as the "admission-line" *ab*. The adiabatic line *km* is shown by the falling "expansion-line" *bc*, which shows the relation between pressure and volume after the steam is cut off. The line *ms* becomes the "exhaust-line" *cd* on our new diagram, representing the steam pressure while the steam is being pushed out of the cylinder. Near the end of the return stroke of the piston, the exhaust valve closes and the steam remaining in the cylinder is compressed by the piston. This process, nearly adiabatic, is shown by the line *da*, corresponding to the line *sp* on the other diagram.

A pressure-volume diagram like the above is called an **indicator card.** It is very valuable in determining the power and performance of engines.

Compound Engines. Since the efficiency of a heat engine is evidently much improved by extending the range of temperature through which it works, and since we have also seen that it takes but little more fuel to produce a pound of high-pressure steam than a pound of low-pressure steam, it should now be clear that it is economical of fuel to use the highest pressures practicable, and to expand the steam as much as possible. But for certain reasons, discussed fully in the Instruction Papers on the Steam Engine, it is advisable to divide the expansion among two, three or even four cylinders, according to the initial steam pressure. Such engines are called compound, triple or quadruple-expansion, and are usually worked with a condenser. In such cases, while the first or high-pressure cylinder is intensely hot, the last or low-pressure cylinder is scarcely more than uncomfortably warm to the hand. The difference represents the heat spent in expansion, a part of which has gone to produce the useful work done by the engine, and a part of which is wasted.

The Hot-Air Engine. There are many forms of these machines, but their general principle varies little. A quantity of air is heated in an iron chamber over a fire, and then is allowed to expand behind a piston, doing work. At the end of the stroke the air is transferred, either by a pump or an auxiliary piston, to a cold chamber, kept cool by air or running water. On the next stroke the air, reduced in volume by its cooling, is forced by the pump into the hot chamber, where it is again heated and the cycle repeated.

Hot-air engines are economical in operation, but necessarily bulky for the amount of power produced. An examination of Fig. 13 will show why this must be so. The heat which must be supplied to the cylinder for every stroke of the piston is represented by the areas C + D, no matter what substance is used as a carrier. But since the heat capacity of air is very small compared with that of steam, the cylinder of the hot-air engine must necessarily be much larger than that of the steam engine for equal power. For this reason hot-air engines are used only in comparatively small powers. The hot-air engine may indeed work between wider temperature limits, but this is not enough to offset the difference between steam and air as carriers of heat.

The Gas Engine. In the gas engine, so called, the energy is derived from the rapid combustion or explosion of a mixture of gas or gasoline vapor and air. In one form of engine the cycle of operations is as follows: A forward stroke of the piston draws into the cylinder a mixture of gas and air in such proportions as to make an explosive mixture. On the return stroke the "charge" is compressed. At or near the end of the stroke, the mixture is exploded, usually by a properly-timed electric spark, and the pressure within the cylinder rises to a high value. The piston is driven forward by the expansion of the hot gases, doing useful work at the expense of the heat-energy in them. At the end of the stroke the exhaust valve opens, and on the second return stroke the burnt gases are pushed out of the cylinder.

The above cycle is often called the **Otto cycle.** For engines working in this way there is thus only one working stroke in every four, and they must be provided with a very heavy fly wheel. Some engines are arranged to have every alternate stroke a working stroke. These are commonly called two-cycle engines, and are much used in propelling boats.

The gas engine has the thermodynamic advantage of working between very wide temperature limits, but is nevertheless subject to serious losses. It is not practicable to expand the exploded charge down to the atmospheric pressure; the gases are discharged while still possessing much available energy. This may be noticed in the sharp, barking exhaust from a gas engine unprovided with a muffler. But the most serious loss is in the transmission of heat to the cylinder walls. This loss is also present in the steam engine, but to a small extent may be recovered. In the gas engine, however, it is practically all wasted.

REFRIGERATING MACHINES.

The cooling produced by the evaporation of a volatile liquid has a very important application in refrigerating machinery.

Ammonia is generally used as the working substance, because it is cheap and satisfactory.

Fig. 15 shows the essential parts of a compression machine. The *compressor* A, kept cool by a jacket of running water, draws ammonia vapor through the valve *a*, compresses it highly and sends it through the valve *b* to the *condenser* B. This is a coil of pipe, also kept cool by running water; and it serves to condense the ammonia, which collects in the bottom coils. The valve D admits the liquid ammonia to the *vaporizer* C, which is also made of pipe coils. In these it vaporizes and falls much below the freezing point of water. (It is well here to refer back to the experiment described on page 16.)

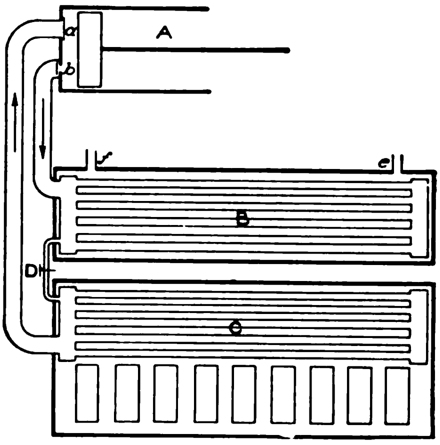

Fig. 15.

Many gases can be liquefied and used in this way; ammonia, carbonic acid and sulphurous anhydride (sometimes called sulphurous acid) in the liquid state, are regular articles of commerce.

In ice making, the vaporizer coils are immersed in a tank of strong brine. The water to be frozen is put into thin metal cans, which are then set into the cold brine, as represented in the figure.

In this way the heat liberated from the water in freezing is carried away by the ammonia vapor, and finally discharged into the cooling water circulating around the compressor and condenser. But since this is at a higher temperature than the source of the heat, the machine is not self-acting. It requires power to operate it, which is expended in compressing the vapor in A.

Instead of drawing the vaporized ammonia back into the pump cylinder, it may be absorbed by cold water, for which it has a strong affinity. Such a machine is called an *absorption machine*, and Fig. 16 shows the principle of a continuously operating absorption machine. The *generator* B contains a concentrated solution of ammonia in water, from which the ammonia is expelled by heat. The *condenser* C is a pipe coil, kept cool by running water, in which the ammonia condenses to the liquid state as soon as its pressure rises to the necessary value. The regulating valve V allows the condensed ammonia to escape to the *refrigerator* I, which corresponds to the vaporizer C of the compression apparatus. The *absorber* A is a tank of cold water in which the gaseous ammonia from I is absorbed. The pipes connecting A and B are arranged to take the most concentrated solution from A to B, and to return to A the water from which the ammonia has been driven. This is effected by the pump P.

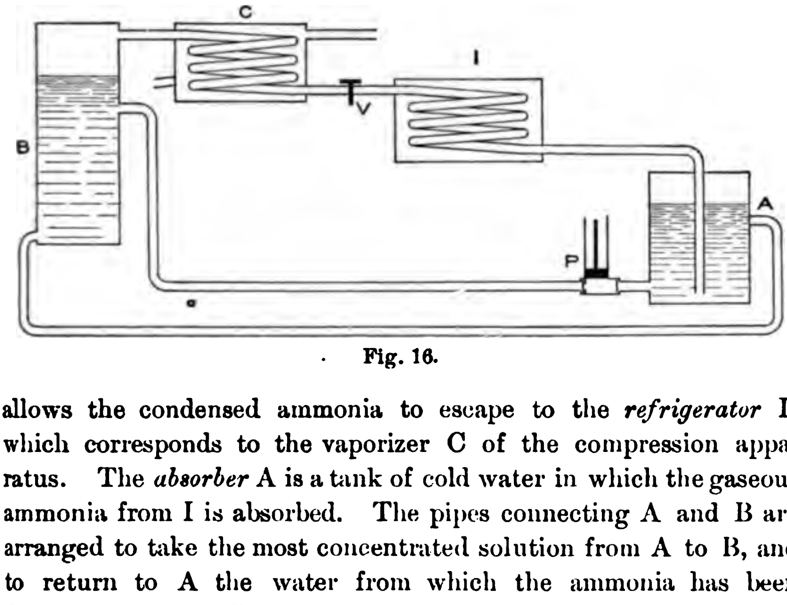

Fig. 16.

In practice the generator B is placed over a furnace, and arrangements are also made for transferring heat from the hot liquid flowing from B to A into the cold liquid flowing from A to B.

LIQUEFACTION OF AIR.

That work done in compressing a gas heats the gas, is a fact familiar to every one who uses a bicycle pump. Similarly, the expansion of a gas against atmospheric or other pressure is accompanied by as decided a cooling. This may readily be observed by holding the finger in the jet of air escaping from a bicycle tire valve. By suitable applications of this principle, it is possible to produce the most intense cold.

One of the simplest methods of liquefying air is shown in principle in Fig. 17. After thorough drying, the air to be liquefied enters through the pipe *a*, and in the compressor C is compressed to about 200 atmospheres (1 atmosphere = 14.7 pounds per square inch). R is a water cooler, to remove the heat of compression. The air thus cooled and strongly compressed passes down through the inner tube of the helical coil H to a valve below.

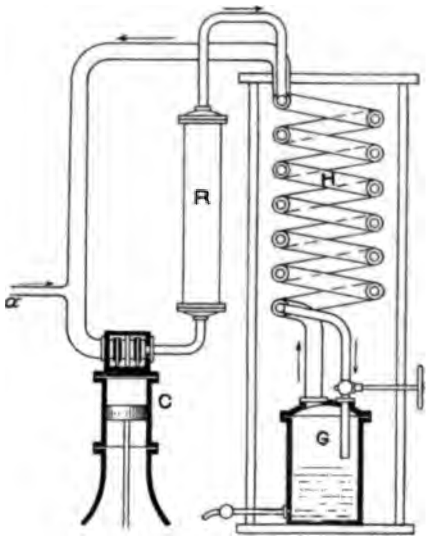

Fig. 17.

Through this valve it escapes into the reservoir G, the expansion producing a considerable fall in temperature. The cold air then passes from the reservoir up through the outside tube of the helical coil, which surrounds the tube down which the air comes, thus cooling the compressed air in the inner tube. This cooled air is allowed to escape in its turn, becoming still colder by its expansion. As the process continues the temperature falls until liquid air begins to collect in the bottom of G, from which it may be drawn off.

With a 3-horse-power engine the yield is about a quart of liquid air per hour.

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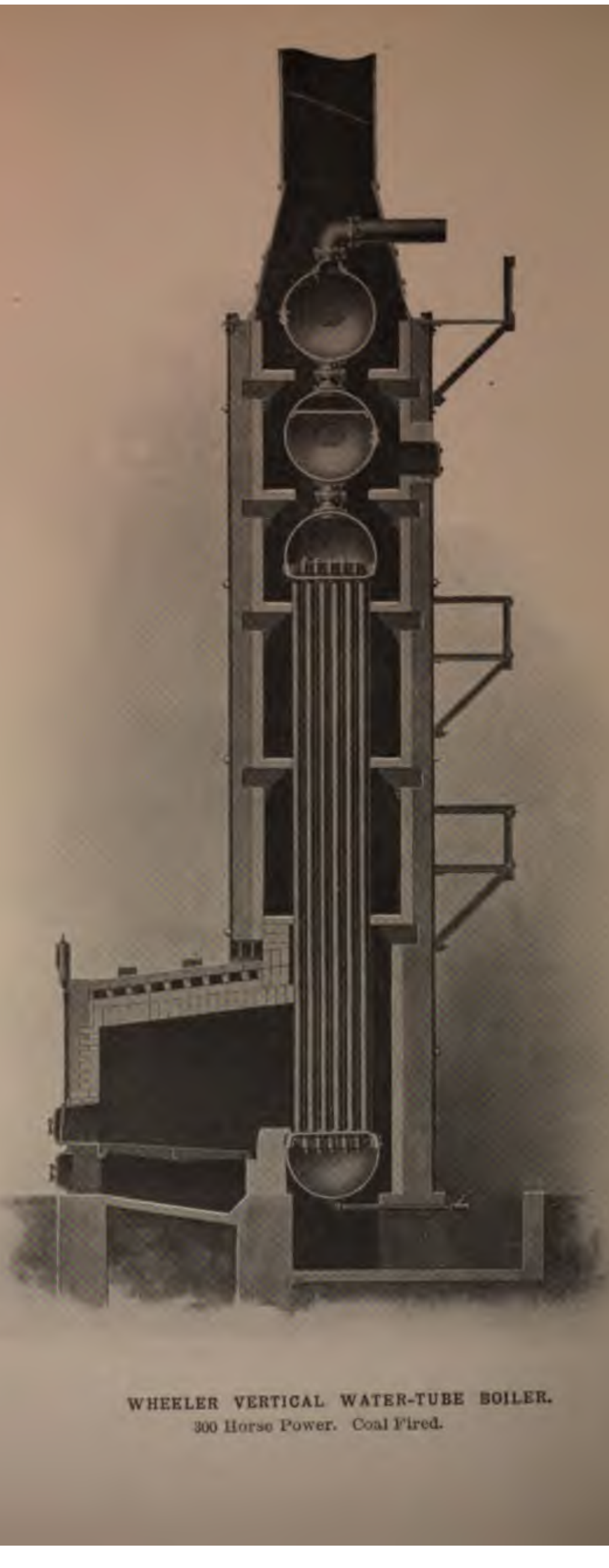


WHEELER VERTICAL WATER-TUBE BOILER.
300 Horse Power. Coal Fired.

CHEMISTRY.

Chemistry is the science which treats of matter in its simplest forms, and the combinations of these forms which make up all material substances.

All animal and vegetable matter, and the solid rock and earthy substances which make up the earth's crust, undergo their changes according to chemical laws. The same is true of water and all other liquids, and of air and gases.

Thus we see that Chemistry relates to an enormous number of substances. The number of the various kinds of substances which exist on the earth is so great that they have never even been counted. Probably there are many substances in the common every-day things of life that have not yet been recognized by the most skilful chemists. However, many compounds have been described, and the chemical laws now known are of great value in finding out the composition of various substances.

The rudiments of Chemistry may be traced back to the ancient Egytians. The Arabs and Greeks sought to change metals into gold and searched for a liquid which would cure all ills and confer the blessing of perpetual life. These experimenters were called **Alchemists.**

During the second period in the history of Chemistry, chemical changes were said to be caused by a substance called **Phlogiston.** This substance was thought to be contained in all combustible matter, and the theory that fire showed the escape of phlogiston was upheld by the most learned chemists of the time.

The phlogiston theory was given up when Lavoisier, a French chemist, demonstrated his theories of combustion and chemical union. On account of his important experiments and discoveries, he is called the "father of Chemistry." Lavoisier proved that when combustible substances are burned, they combine with a gas called oxygen, forming new substances.

The chemist can take carbon out of sugar, but he cannot take anything but carbon out of carbon. He can take oxygen out of sugar, but he cannot take anything but oxygen out of oxygen.

The science of Chemistry shows that all substances are made up of various combinations of simple forms of matter, which cannot, by any known means, be divided into other kinds of matter. Thus, sugar is a compound or combination of simple forms, and the simple forms carbon, oxygen, and hydrogen are called **elements.**

An element may be defined as being *a form of matter which chemists have not yet been able to break up into other forms of matter.*

The thousands of words in the English language are made up of combinations of letters of which there are less than thirty. The letters are the simple forms, or elements, and the words are the combinations, or substances. The millions of substances found on the earth are made up of various combinations of about seventy elements. The exact number of elements is not known, and new ones are being discovered from time to time.

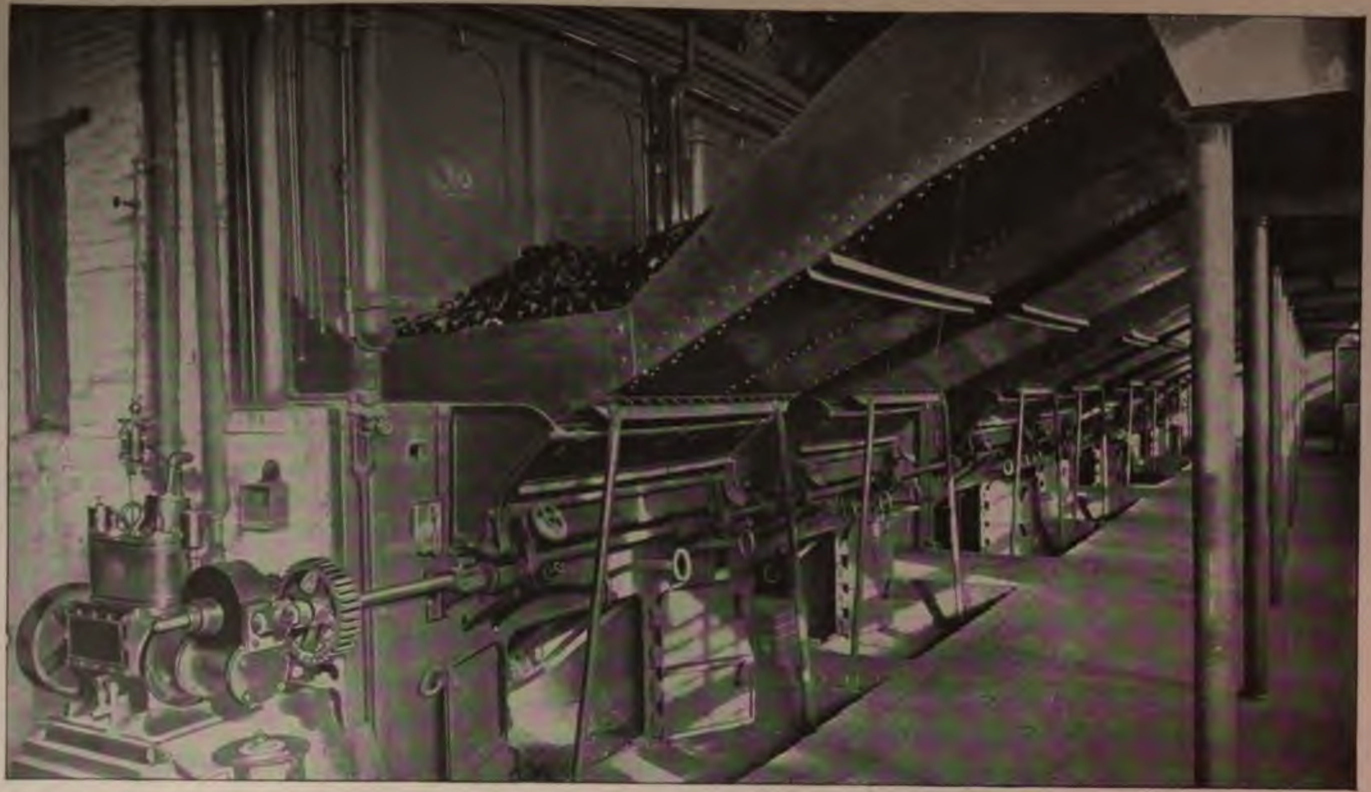
The table on the opposite page gives a partial list of elements, their symbols or abbreviations, their atomic weights, their physical conditions at ordinary temperature and their specific gravities.

A large proportion of the elements are uncommon. Carbon, copper, gold, iron, lead, mercury, nickel, phosphorus, silver, suphur, tin, zinc, oxygen and nitrogen are almost the only ones that are familiar to most people.

Almost all of the elements exist in very small quantities. It has been estimated that an amount equal to ninety-nine one-hundredths of the solid, liquid and gaseous matter of the globe is made up of only thirteen elements, the remaining 60 (about) elements comprising only one one-hundredth.

SYMBOLS OF ELEMENTS.

Each element, or strictly speaking, each minute quantity of an element (called an atom) is designated by a letter, or a few letters, called its symbol. For most elements, the symbols are the initial letters of the names, thus for carbon, we write C, for



Roney Mechanical Stoker, Showing Coal Delivery Shutes and Operating Engine.

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ELEMENTS.

Names.	Symbol.	Atomic Weight.	Physical condition at ordinary temperature.	Specific Gravity
Aluminum	$\mathrm{Al}^{\mathrm{IV.}}$	27.	Solid	2.60
Antimony	$\mathrm{Sb}^{\mathrm{III,\ V.}}$	120.	"	6.71
Argon	A	20 (?)	Gas	—
Arsenic	$\mathrm{As}^{\mathrm{III,\ V.}}$	75.	Solid	5.73
Barium	$\mathrm{Ba}^{\mathrm{II.}}$	137.	"	3.75
Bismuth	$\mathrm{Bi}^{\mathrm{III,\ V.}}$	208.	"	9.80
Boron	$\mathrm{B}^{\mathrm{III.}}$	11.	"	2 5 (?)
Bromine	$\mathrm{Br}^{\mathrm{I,\ V.}}$	80.	Liquid	3.187
Cadmium	$\mathrm{Cd}^{\mathrm{II.}}$	112.	Solid	8.60
Caesium	$\mathrm{Cs}^{\mathrm{I.}}$	133.	"	1.88
Calcium	$\mathrm{Ca}^{\mathrm{II.}}$	40.	"	1.57
Carbon	$\mathrm{C}^{\mathrm{IV.}}$	12.	"	3.5–.6
Cerium	$\mathrm{Ce}^{\mathrm{III,\ IV.}}$	141.	"	6.68
Chlorine	$\mathrm{Cl}^{\mathrm{I,\ V.}}$	35.5	Gas	2.450
Chromium	$\mathrm{Cr}^{\mathrm{IV,\ VI.}}$	52.	Solid	6.50
Cobalt	$\mathrm{Co}^{\mathrm{II,\ IV.}}$	59.	"	8.5–.7
Copper	$\mathrm{Cu}^{\mathrm{II.}}$	63.3	"	8.95
Fluorine	$\mathrm{F}^{\mathrm{I.}}$	19.	Gas	1.313
Gold	$\mathrm{Au}^{\mathrm{I,\ III.}}$	196.5	Solid	19.32
Hydrogen	$\mathrm{H}^{\mathrm{I.}}$	1.	Gas	0.069
Iodine	$\mathrm{I}^{\mathrm{I,\ V.}}$	127.	Solid	4.948
Iridium	$\mathrm{Ir}^{\mathrm{II,\ IV,\ VI.}}$	193.	Solid	22.42
Iron	$\mathrm{Fe}^{\mathrm{II,\ IV,\ VI.}}$	56.	"	7.86
Lead	$\mathrm{Pb}^{\mathrm{II,\ IV.}}$	207.	"	11.37
Magnesium	$\mathrm{Mg}^{\mathrm{II,\ IV,\ VI.}}$	24.	"	1.74
Manganese	$\mathrm{Mn}^{\mathrm{II.}}$	55.	"	8.03
Mercury	$\mathrm{Hg}^{\mathrm{II.}}$	200.	Liquid	13.55
Nickel	$\mathrm{Ni}^{\mathrm{II,\ IV.}}$	58.	Solid	8.90
Nitrogen	$\mathrm{N}^{\mathrm{III,\ IV.}}$	14.	Gas	0.971
Oxygen	$\mathrm{O}^{\mathrm{II.}}$	16.	"	1.105
Phosphorus	$\mathrm{P}^{\mathrm{I,\ III,\ V.}}$	31.	Solid	Colorless 1.83 Red 2.20
Platinum	$\mathrm{Pt}^{\mathrm{II,\ IV.}}$	195.	"	21.50
Potassium	$\mathrm{K}^{\mathrm{I.}}$	39.	"	0.87
Silicon	$\mathrm{Si}^{\mathrm{I.V}}$	28.	"	2.39
Silver	$\mathrm{Ag}^{\mathrm{I.}}$	108.	"	10.53
Sodium	$\mathrm{Na}^{\mathrm{I.}}$	23.	"	0.978
Strontium	$\mathrm{Sr}^{\mathrm{II.}}$	87.5	"	2.54
Sulphur	$\mathrm{S}^{\mathrm{II,\ IV,\ VI.}}$	32.	"	2.05
Tin	$\mathrm{Sn}^{\mathrm{II,\ IV.}}$	118.	"	7.29
Tungsten	$\mathrm{W}^{\mathrm{IV,\ VI.}}$	184.	"	19.12
Uranium	$\mathrm{U}^{\mathrm{IV,\ VI.}}$	239.8	"	18.70
Zinc	$\mathrm{Zn}^{\mathrm{II,}}$	65.	"	7.15

NOTE: The Roman numerals in the second column denote the valence of the element.

hydrogen H, for phosphorus P, etc. Some of the elements have symbols derived from their Latin or Greek names. Thus Au is the symbol for gold, because its Latin name is aurum; similarly Pb signifies lead, since its Latin name is plumbum. In the table, it will be noticed that there are nine elements whose names begin with the letter C. To avoid confusion, carbon has for its symbol, C, and the symbols of the other eight contain an additional distinguishing letter.

As we have said, the symbol stands for one atom. If more than one atom of an element is to be indicated, a subscript or sub-exponent is used. A coefficient is also frequently used to express a number of atoms of the same element. Thus 2Na or Na_2 means two atoms of sodium; and three atoms of iron may be indicated thus, Fe_3 or 3Fe.

Certain groups of atoms remain the same in a series of chemical compounds. To denote a number of these characteristic groups a parentheses and sub-exponent is used. The sub-exponent multiplies all the atoms inside of the parentheses; thus, $(OH)_4$ means four "hydrate" groups, or four atoms of oxygen and four of hydrogen, or O_4H_4.

We may have a molecule of a substance whose atoms are of different elements. Suppose we wish to indicate a molecule of a substance which is made up of one atom of sodium and one atom of chlorine. An atom of sodium is written Na and an atom of chlorine is written Cl. The molecule is indicated by writing the symbols close together as NaCl. A molecule composed of one atom of silver, one of nitrogen, and three of oxygen is written $AgNO_3$.

In case we desire to express 5 molecules of a compound, each molecule containing two atoms of hydrogen, one atom of sulphur and four atoms of oxygen, we write $5H_2SO_4$. This could be written $5\,(H_2SO_4)$. As in arithmetic or algebra, the coefficient 5 means that in the 5 molecules of H_2SO_4 there are $5 \times 2 = 10$ atoms of hydrogen, $5 \times 1 = 5$ atoms of sulphur, and $5 \times 4 = 20$ atoms of oxygen.

Thus it is seen that the sub-exponent applies only to the element which it follows, but a coefficient multiplies all the elements in the compound. In this way Chemistry resembles algebra. Again, let us examine the formula, $Cu(NO_3)_2$. The sub-exponent 2 applies to the parentheses and $Cu(NO_3)_2 = CuN_2O_6$; and $(NH_4)_2SO_4$ is the same as $N_2H_8SO_4$.

EXAMPLES FOR PRACTICE.

1. Give names for the following: Cu, Fe, S, Ni, O, Ag, Sn, Al and Zn.

2. Name these elements and state the indicated number of atoms of each; C_7, 3Ni, 4Pt, S_2, Sn_5, O_3 and 2H.

3. Write symbols for 4 atoms of phosphorus, 6 atoms of mercury, 3 atoms of iron and 5 atoms of carbon.

4. How many molecules in each of the following, and how many atoms of each element? 6HgO, $2CaCl_2$, $3Ca(PO_4)_2$, $2Fe_2(SO_4)_3$, $3Bi_2O_3$.

ATOMIC WEIGHT.

When we say that the specific gravity of lead is 11.37, we mean that lead is 11.37 times as heavy as water. In computing specific gravity we find the weight of a given volume of the substance, and the weight of an equal volume of water. By dividing the weight of the substance by the weight of an equal volume of water, we get the specific gravity. In other words, water is used as the standard or unit when finding specific gravity.

For gases, air is used instead of water. That is, if a gas has a specified gravity of 1.103, it is 1.103 times as heavy as an equal volume of air. In the table on page 7 the specific gravities of solid and liquid elements are referred to water as the standard, and the specific gravities of gaseous elements are referred to air as the unit.

Suppose we could compare an atom of oxygen with an atom of hydrogen; we would find that the atom of oxygen weighed 16 times as much as an atom of hydrogen. Also, if 1000 atoms of iron are compared with 1000 atoms of hydrogen, the iron will be found to be 56 times as heavy as the hydrogen. Since atoms are compared, this relation is called **atomic weight.**

Hydrogen is taken as the unit because its atom weighs less than an atom of any other substance.

The atomic weight of an element is the weight of its atom in terms of the weight of an atom of hydrogen, which is the standard or unit.

From the table we find that the atomic weight of carbon is 12, of nitrogen 14, and of lead 207.

It is impossible to see an atom, even with the most powerful optical instruments; therefore, it cannot be weighed. However, chemists have determined the atomic weights of the elements by comparing their compounds.

It is assumed that equal volumes of all gases have the same number of molecules if the temperature and pressure are alike. This assumption or law is the foundation of the chemical theory of to-day, and it is accepted by chemists generally.

If a gallon of nitrogen and a gallon of hydrogen are weighed (temperature and pressure constant), the ratio of the weight of the nitrogen to that of the hydrogen is the density of nitrogen. Since both are gases, it is called **vapor density.**

We may define vapor density as follows: *The vapor density of any gas is the weight of a given volume of it in terms of the weight of an equal volume of hydrogen at the same temperature and pressure.*

In making this computation, the gases must be of the same temperature because heat causes gases to expand, and the gas weighed at the higher temperature will contain fewer molecules.

The pressure also must be the same, for the greater the pressure, the greater the number of molecules in a given volume.

At a certain temperature and pressure, a gallon of hydrogen weighs .3264 grams and at the same temperature and pressure a gallon of oxygen weighs 5.2224 grams. The oxygen is consequently $\frac{5.2224}{.3264} = 16$ times heavier than the hydrogen. Then the vapor density of oxygen is 16.

The molecular weight of a gas is twice its vapor density. In other words, the vapor density is one-half the molecular weight. Then, as the vapor density of oxygen is 16, the molecular weight is $2 \times 16 = 32$. If there are two atoms in a molecule of oxygen, and the molecular weight is 32, the atomic weight is $\frac{32}{2} = 16$.

Thus for oxygen, the atomic weight and vapor density are the same, 16 ; but if there are three or four atoms in the molecule of an element, the atomic weight, being equal to the molecular weight divided by the number of atoms, will not equal the vapor density.

Let us consider the gas called carbon dioxide. We write the symbol CO_2 because it is made up of two parts oxygen and one part carbon. The atomic weight of carbon is, from the table, 12; the atomic weight of oxygen is 16, and as there are two atoms of oxygen and one of carbon in the molecule, the molecular weight is

$$12 + (2 \times 16) = 44.$$

The vapor density is one-half the molecular weight, or 22.

By finding the vapor density of gases, chemists have calculated the atomic and molecular weights. This method cannot however be used for some elements, as many substances have never been vaporized or cannot be vaporized under conditions which make weighing possible. For these elements the vapor densities, molecular and atomic weights are uncertain.

Another method is as follows: The atom is the smallest particle which can exist in composition or combination. Hence, the atomic weight is the *least combining weight.* By analyzing a great number of compounds, the smallest weight of an element is determined, and the other compounds contain a multiple of that weight. The least combining weight is the atomic weight.

The vapor density as found by one method and the atomic weight by another are generally the same, that is, if there are two atoms in the molecule. The vapor of mercury has a vapor density of $99\frac{1}{2}$, hence a molecular weight of 199. But the atomic weight is 199, hence there is one atom in a molecule.

MOLECULAR WEIGHT.

The weight of a molecule is found by adding together the weights of all the atoms in the molecule. Molecular weight, like atomic weight, is expressed in terms of the weight of the hydrogen atom.

We know that a molecule of common salt is composed of one atom of sodium, and one atom of chlorine. The sodium atom is 23 times as heavy as the hydrogen atom, or, its atomic weight is

23. The atomic weight of chlorine is 35.5. Therefore the molecular weight of a molecule of salt is 23 + 35.5 = 58.5. In other words a molecule of salt $NaCl$ is 58.5 times as heavy as an atom of hydrogen. Three molecules $3NaCl$, weigh 175.5.

What is the molecular weight of copper nitrate, $Cu(NO_3)_2$? As we have seen, $Cu(NO_3)_2$ is the same as CuN_2O_6. This molecule is then made up of one atom of copper weighing 63.3, two atoms of nitrogen weighing $2 \times 14 = 28$, and six atoms of oxygen weighing $6 \times 16 = 96$. The molecular weight is $63.3 + 28 + 96 = 187.3$. Sometimes copper nitrate, in common with many other substances, has a crystalline form represented by $Cu(NO_3)_2 \cdot 3H_2O$. The $3H_2O$ is an essential part of the crystal, called "water crystallization" and must be added when finding the molecular weight. As $3H_2O = 3(2 + 16) = 54$, the molecular weight of crystallized copper nitrate $Cu(NO_3)_2 \cdot 3H_2O$ is $187.3 + 54 = 241.3$.

CHEMICAL AFFINITY.

In order that molecules may be formed from atoms, there must be some force to bind the atoms together. This force is called *chemical affinity* or *chemism*. This force corresponds to the physical force called cohesion.

A compound usually possesses properties which are entirely different from those of the elements of which it is composed. Water, for instance, is made up of two gases, hydrogen and oxygen. These two substances are gases, colorless and ordorless. When combined in the proper proportion, the compound is a liquid at ordinary temperatures.

Sugar ($C_{12}H_{22}O_{11}$), a white, sweet, crystalline substance, is formed by combining carbon, a black non crystalline substance, with oxygen and hydrogen, two colorless and odorless gases.

Of the constituent elements of cupric sulphate, $CuSO_4 \cdot 5H_2O$, copper is red, sulphur yellow, oxygen and hydrogen are colorless. Two are gases and two are solids. The cupric sulphate thus formed is a blue solid.

Chemical affinity takes away the properties of the elements and causes the compound to have new properties. Chemical affinity may act between atoms of the same kind, or atoms of different kinds. Also, it may be strong or weak, but it acts only at short distances.

It is easy to separate the carbon from the other two elements in sugar, but it is more difficult to resolve water into its elements, hydrogen and oxygen. In other words, it is hard to break up the attraction that some elements have for others, but it can be done by heat, electricity and reagents. A **reagent** is a substance which produces chemical change such as an acid.

COMPOUNDS.

Chemical affinity binds atoms together to form molecules and compounds. Compounds are usually called by names taken from the elements of which they are composed, as hydrogen oxide, H_2O, (*water*), and carbon dioxide, CO_2.

Some compounds are composed of two elements as NaCl, chloride of sodium (*common salt*), and HCl, hydrogen chloride or *hydrochloric acid.* Other compounds contain three elements, as H_2SO_4 sulphate of hydrogen or *sulphuric acid*, and KOH, potassium hydrate.

UNION BY WEIGHT.

Before taking up the study of compounds and equations it will be necessary to understand the proportions in which elements combine. This study is based upon the two fundamental laws of chemistry which are as follows:

1. The law of Conservation of Matter.
2. The law of Definite Weight.

Law of Conservation of Matter. — *The sum of the weights of all the products in an experiment is exactly equal to the sum of the weights of all the factors.*

This law means that matter can neither be destroyed nor created. In other words, matter may be changed or transformed; it may be changed from solid to liquid or to invisible gas, or the volumes may be greatly increased, but the processes do not cause any loss or gain in weight.

Law of Definite Weight. — *Any chemical compound always contains the same elements in the same ratio by weight.*

Ferrous sulphide, FeS, always contains iron and sulphur, and always in the same proportion by weight. Thus, FeS is always made up of 56 parts of iron and 32 parts of sulphur. Potassium chlorate, $KClO_3$, always contains potassium, chlorine and oxygen. Also, in the compound, there are 39 parts (by weight) of potassium, K; 35 parts of chlorine, Cl; and $3 \times 16 = 48$ parts of oxygen, O.

Water is made from oxygen and hydrogen. Pure water always contains 8 parts oxygen (by weight) and 1 part hydrogen.

Suppose we wish to make oxygen from the compound, potassium chlorate, $KClO_3$. How much oxygen can we expect from 2 ounces?

First, we must know what proportion of the $KClO_3$ is oxygen. We know that there are 39 parts K, 35 parts Cl, and 48 parts O. Then of 122 parts, 48 are oxygen, and $\frac{48}{122} \times 2 = .787$ ounces (nearly).

VALENCE.

Atoms of the various elements differ in the number of atoms of other elements which they can hold in combination to form chemical compounds. Let us suppose that atoms have "hands" or "hooks" with which they can grasp other atoms. Some atoms have one hand, some two, some three, and so on. It is evident that an atom with two hands can hold two atoms having one hand, or it can hold one atom which has two hands, etc. Or we may consider that an atom has a certain number of "affinity points." The number of these affinity points determines the number of atoms which it can hold in chemical combination. This is what is known as the *valence* or quantivalence of an atom. Valence has no apparent relation to the strength of the affinity of atoms.

We must have a standard by which to measure valence. The combining power of hydrogen is a convenient measure of valence as its valence is always 1; in other words it seems to have but one "affinity point," or "hand." With elements which combine directly with hydrogen the valence is the number of hydrogen atoms which one atom will hold. Atoms which do not combine with H will usually replace H in its compounds and the number of atoms of H which such an atom will replace is its valence. Thus in NaCl the Na replaces one atom of H in HCl. Hence the valence of Na is 1. In H_2O one atom of O combines with two atoms of H, therefore the valence of O is 2. We may say that the hydrogen atom has one hook; two atoms must therefore have two hooks, and as oxygen is combined with two atoms of hydrogen, the oxygen element must have two hooks. Hence the valence is two. Fig. 1 shows some of the ways of representing the valences of elements.

Ammonia is a gas made up of three atoms of hydrogen and one atom of nitrogen; its symbol is then NH_3. What is the valence of N? The valence of hydrogen is one, and as one atom of nitrogen combines with three atoms of hydrogen, the valence of nitrogen must be three.

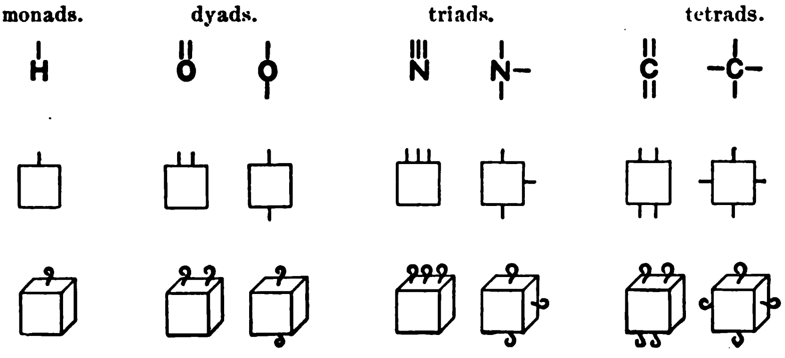

Fig. 1.

What is the valence of sodium, magnesium, bismuth and carbon from these symbols?

$$NaCl, MgCl_2, BiCl_3, CCl_4.$$

In NaCl, it is seen that one atom of sodium, Na, combines with one atom of Cl, hence its combining power is one. Again, we have the two compounds HCl and NaCl. From these symbols it is seen that one atom of Na replaces one atom of H, therefore the replacing value of Na is one.

In magnesium chloride, $MgCl_2$, one atom of magnesium combines with two atoms of chlorine. The valence of Mg is therefore two.

Chloride of bismuth, $BiCl_3$, is made up of one atom of bismuth and three atoms of chlorine. Then as one atom of Bi combines with three atoms of Cl the combining value of Bi is three.

Similarly four atoms of chlorine are necessary when combining with one atom of carbon, and the valence of C is four.

If these compounds were made by the action of HCl, the equations would be

$$\begin{aligned}
\mathrm{Na} &+ \mathrm{HCl} = \mathrm{NaCl} + \mathrm{H}.\\
\mathrm{Mg} &+ 2\mathrm{HCl} = \mathrm{MgCl_2} + 2\mathrm{H}.\\
\mathrm{Bi} &+ 3\mathrm{HCl} = \mathrm{BiCl_3} + 3\mathrm{H}.\\
\mathrm{C} &+ 4\mathrm{HCl} = \mathrm{CCl_4} + 4\mathrm{H}.
\end{aligned}$$

When an element combines with hydrogen, atom for atom, or replaces hydrogen, atom for atom, its valence is one and it is called *univalent.* The *bivalent* elements are those which require two atoms of hydrogen to replace one atom of the element, and the *trivalent* elements are those whose atoms select three atoms having a valence of one with which to unite. These elements are called monads, dyads and triads, etc.

Some elements have more than one valence. Phosphorus sometimes combines with three atoms of chlorine (PCl_3) and sometimes with five atoms (PCl_5). In the first case P is a triad, and in the second case a pentad.

The valence of an element is often indicated by marks at the right, as Na', Cu'', Bi''', C^{iv}.

EQUATIONS.

A chemical equation (sometimes called a reaction) is a short algebraic expression of a chemical change. If we heat together iron filings and sulphur, the result is iron sulphide, or we can say that

iron + sulphur = iron sulphide.

We know that a definite quantity of iron united with a definite quantity of sulphur, and the result was a definite quantity of iron sulphide. We may say that one atom of sulphur united with one atom of iron and formed a molecule of iron sulphide. Let us use the symbols of these elements and we can write,

$$\mathrm{Fe} + \mathrm{S} = \mathrm{FeS}.$$

In fact, millions of atoms of iron united with an equal number of atoms of sulphur; but for simplicity and brevity, we write the equation for one atom of each.

The atomic weight of iron is 56, and that of sulphur is 32. Then 56 parts, by weight, of iron united with 32 parts by weight, of sulphur, to form 88 parts of iron sulphide.

$$\begin{array}{ccc} \textbf{Factors.} & & \textbf{Product.} \\ Fe + S & = & FeS \\ 56 + 32 & = & 88 \end{array}$$

An equation represents the substances that are put together, and the substances obtained. Also, it shows the proportions of those used and of those obtained. Substances put together are called Factors, and those obtained Products. The factors are usually placed on the left-hand side of the equality sign, and the products on the right-hand side.

From the law of conservation of matter, we learned that matter cannot be created or destroyed. Therefore there must be as many atoms in the products as there were in the factors. Also there must be the same number of each kind of atoms on both sides of the equation.

Take the action of hydrochloric acid, HCl, on metallic zinc, Zn; the zinc disappears and bubbles of gas are given off.

$$Zn + HCl = ?$$

We know that hydrogen is given off. The valence of Zn is two, or, one atom of Zn will replace two atoms of H; but there is only one atom of H in one molecule of HCl; therefore we must have two molecules of HCl to give two atoms of H to be replaced. The equation (or reaction) then will be:

$$\begin{array}{llcl} & \textbf{Factors.} & & \textbf{Product.} \\ & Zn + 2HCl & = & ZnCl_2 + 2H \\ \text{by atoms} & 1 + [2 \times (1 + 1)] & = & (1 + 2) + 2 \\ \text{or} & 1 + 4 & = & 3 + 2 \end{array}$$

The zinc replaces the hydrogen and combines with the chlorine, forming zinc chloride, $ZnCl_2$, and the hydrogen gas is set free. It is evident that there are five atoms on each side of the equation, also that on each side one of these is an atom of Zn, two are atoms of H and two are atoms of Cl.

Suppose sulphuric acid, H_2SO_4, is added to caustic soda, $NaOH$. Sulphate of soda, Na_2SO_4, and water, H_2O, will be formed.

$$NaOH + H_2SO_4 = Na_2SO_4 + H_2O — ?$$

We see that there are two atoms of Na in the products and only one in the factors, also three atoms of H on the left and only two on the right; therefore we must have two molecules of NaOH to furnish two atoms of Na, and the expression will then become

$$2NaOH + H_2SO_4 = Na_2SO_4 + 2H_2O$$

By atoms

$$2\times(1+1+1)+(2+1+4)=(2+1+4)+[2\times(2+1)]$$

or

$$6+7=7+6$$

The equation will now balance, for there are thirteen atoms on each side and also the same number of atoms of Na, O, H and S in the factors as in the products.

We may write many chemical equations which do not express chemical reactions. In order to write a true chemical reaction (equation) it must be known that a chemical action takes place and also what substances are formed.

Use of Chemical Equations. From the study of atomic and molecular weights we can find the weights of all factors used and all the products made in terms of the weight of an atom of hydrogen. Let us again consider the equation of the action of HCl on Zn.

$$Zn + 2HCl = ZnCl_2 + 2H$$

By weights this becomes

$$65 + 73 = 136 + 2$$

For the atomic weight of Zn is 65, the molecular weight of HCl $= 1 + 35.5$, and of 2HCl $= 2 \times 36.5 = 73$. The molecular weight of $ZnCl_2 = 65 + (2 \times 35.5) = 136$, and the weight of $2H = 2$.

Example.—How much hydrochloric acid will be required to dissolve 10 pounds of zinc? We see by the chemical equation that 65 parts by weight of zinc are dissolved in 73 parts by weight of HCl. The problem is then one of simple proportion.

Zn · 2HCl : : zinc : hydrochloric acid

65 : 73 : : 10 lbs. : x lbs.

$65x = 730$ $x = 11.23 +$ lbs. hydrochloric acid.

If more zinc is taken, the excess over 10 pounds will be left unacted upon, or if more than 11.23+ pounds of HCl is added to 10 pounds of zinc, the excess HCl will not be used up

Another example: How much zinc chloride, $ZnCl_2$, will be produced from the 10 pounds of zinc?

$Zn : ZnCl_2 :: $ zinc : zinc chloride

$65 : 136 :: 10 : x$

$65x = 1360 \quad x = 21$ lbs. (nearly) of zinc chloride.

Thus we see that if we have the chemical equations and atomic weights we can calculate all the products and factors if we know the weight of one factor or product. This is very important in all chemical work.

EXAMPLES FOR PRACTICE.

(1) Complete the following:

(*a*) $S + ? = SO_2$ (*b*) $Fe + ?HCl = FeCl_2 + ?H$

(*c*) $CaCO_3$ (heated) $= CaO + ?$

(*d*) $Na_2CO_3 + ?HCl = ?NaCl + H_2O + CO_2$

(2) $C + 2O = CO_2$. How much CO_2 (carbon dioxide) will be made from 10 pounds of carbon? Ans. $36\frac{2}{3}$ pounds.

(3) $S + 2O = SO_2$. How much sulphur will be required to make 20 pounds of SO_2? Ans. 10 pounds.

(4) $Na_2CO_3 + H_2SO_4 = Na_2SO_4 + H_2O + CO_2$. How much sulphuric acid will be required to neutralize 12 pounds of sodium carbonate, Na_2CO_3? Ans. 11.1 pounds.

CHEMICAL ACTIONS.

Chemical action does not always take place when substances are mixed; but from countless experiments several general facts governing chemical action can be mentioned. Many of the elements are active chemically. Thus oxygen combines directly (forming oxides) with all elements except florine and argon; sulphur unites with many of the metals, forming sulphides; chlorine, bromine, and iodine form chlorides, bromides and iodides respectively. The oxygen in many compounds is easily separated, making them chemically active. They are called oxidizing agents, and as examples bichromate of potash, nitric acid, potassium chlorate and bleaching powder may be mentioned. Compounds called acids are very active chemically.

An Acid is a compound containing hydrogen which can be easily exchanged for a metal or other basic substance. Acids have a sour taste and cause effervescence when added to a carbonate, as, for instance, baking soda.

Basic Elements are the common metals and elements which act like them. Sodium, potassium and calcium are in reality metals and are much more "basic" than the familiar metals.

An Alkali is formed when a very basic element displaces one atom of hydrogen in H_2O forming a hydrate thus: $Na + H_2O = NaOH + H$. NaOH is called a sodium hydrate.

The hydrogen of an acid is easily exchanged for a metal when treated with an alkali. When the correct proportion of an acid is added to an alkali or other basic compound the characteristic properties of both the acid and base are lost. The acid and alkali are said to neutralize each other.

Salts. The substance formed by neutralizing an acid is called a salt. Water is also formed when a hydrate or an oxide is used to neutralize an acid.

(1) $HCl + KOH = KCl + H_2O$
(2) $2HNO_3 + Ca(OH)_2 = Ca(NO_3)_2 + 2H_2O$
(3) $H_2SO_4 + ZnO = ZnSO_4 + H_2O$.

When a metal is used, hydrogen is set free. Thus:

$$Fe + H_2SO_4 = FeSO_4 + H_2$$

The substances KCl, $Ca(NO_3)_2$, $ZnSO_4$ and $FeSO_4$ are salts, and are neutral substances with little chemical action.

When a volatile substance can be given off, chemical action will usually take place. Strong acids will displace weaker acids in salts; as, for example, $2HCl + FeS = FeCl_2 + H_2S$. Hydrogen sulphide, H_2S, is a gas and is expelled.

$$2HNO_3 + Na_2CO_3 = 2NaNO_3 + H_2O + CO_2.$$

Carbon dioxide, CO_2, is given off when a strong acid is added to a carbonate. Heating frequently assists the action. Nitric acid, HNO_3, is made by heating nitrate of soda with sulphuric acid; and hydrochloric acid, HCl, by heating common salt with sulphuric acid.

The reactions are:

(1) $H_2SO_4 + NaNO_3 = NaHSO_4 + HNO_3$
(2) $H_2SO_4 + 2NaCl = Na_2SO_4 + 2HCl$.

Solutions of all neutral salts can be mixed without apparent chemical action, unlsse an insoluble compound is formed. For example, a solution of common salt can be mixed with a solution of nitrate of soda without change. There are, however, many insoluble salts, of which lead sulphate is one. If a solution of lead nitrate be added to a solution of sodium sulphate, the mixture becomes white like milk, and after a short time a white powder, lead sulphate, $PbSO_4$, settles to the bottom. $Pb(NO_3)_2 + Na_2SO_4 = 2NaNO_3 + PbSO_4$. This is called a *precipitate*, because it is thrown down. The precipitate will continue to form until one or the other of the salts is exhausted.

Solubility. Many substances will dissolve in water, such as salts, acids, alkalis, sugar and gases. If a salt (or sugar) is placed in water, it disappears. If more and more salt is added, a point will at length be reached when no more salt will be dissolved. The solution is then said to be saturated. If, however, the saturated solution is heated, more salt (or sugar) can be dissolved. That is, in most cases heating water increases its capacity for retaining solids in solution. The reverse is true of gases, for more gas can be dissolved in cold water than in hot water.

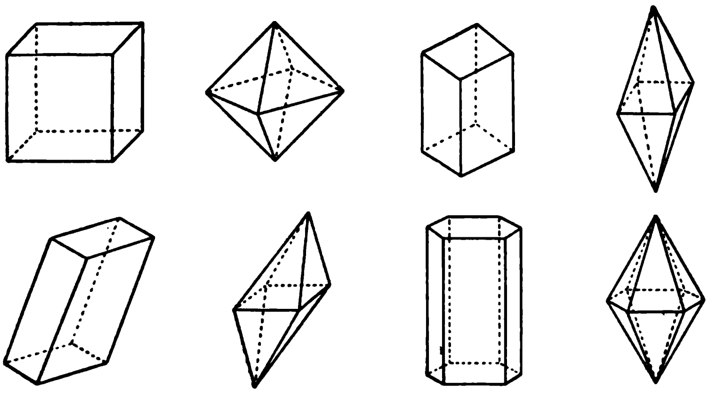

Fig. 2.

If a hot saturated solution of a solid is cooled to ordinary temperature, some of the solid will be thrown out of the solution, or precipitated. The precipitate is often formed in very beautiful crystals, especially if the solution is cooled slowly. A few of the shapes are shown in Fig. 2.

OXYGEN.

Occurrence. — Oxygen is one of the most important elements. It is important because of its abundance, its activity, and the great number of compounds into which it enters. Oxygen makes up by weight fully one-half of the globe, including air, ocean and earth. The air is about one-fifth oxygen by weight; water is eight-ninths oxygen by weight, and the important minerals such as quartz, sand, &c., are about one-half oxygen.

The oxygen in water and in minerals is chemically combined, but when in air, it is simply mixed with the other gases.

Oxygen is essential to all animal matter. It sustains the vitality of man, of beasts and even of fish. Oxygen supports combustion, whether a single splinter is burning. or there is a great conflagration.

Discovery. — The first discovery of oxygen is generally attributed to Dr. Joseph Priestly, an English clergyman and scientist. Priestly performed his great experiment August 1, 1774, and this day has been called the birthday of modern chemistry.

So great was the interest in chemistry at this time, that two others discovered this important element at about the same time that Priestly did. These two were Scheele, an apothecary in Sweden, and Lavoisier, the French chemist. Scheele called it "fire air," but Lavoisier named it oxygen which means "acid former."

Lavoisier in giving the true explanation of combustion overthrew the Phlogiston theory and started modern chemistry.

Physical Properties. — Oxygen is a gas at ordinary temperatures and pressures. It is colorless, tasteless, odorless and a little heavier than air. It is soluble in water; it is to this property that fish owe their existence. About one volume of oxygen can be dissolved in 25 volumes of water.

Oxygen was, until recently, considered a permanent gas, that is, it could not be liquified. Experiments, conducted with apparatus capable of subjecting it to intense cold and great pressure, show that the gas can be liquified.

Chemical Properties. — The most striking of the chemical properties is the tendency to combine with other elementary

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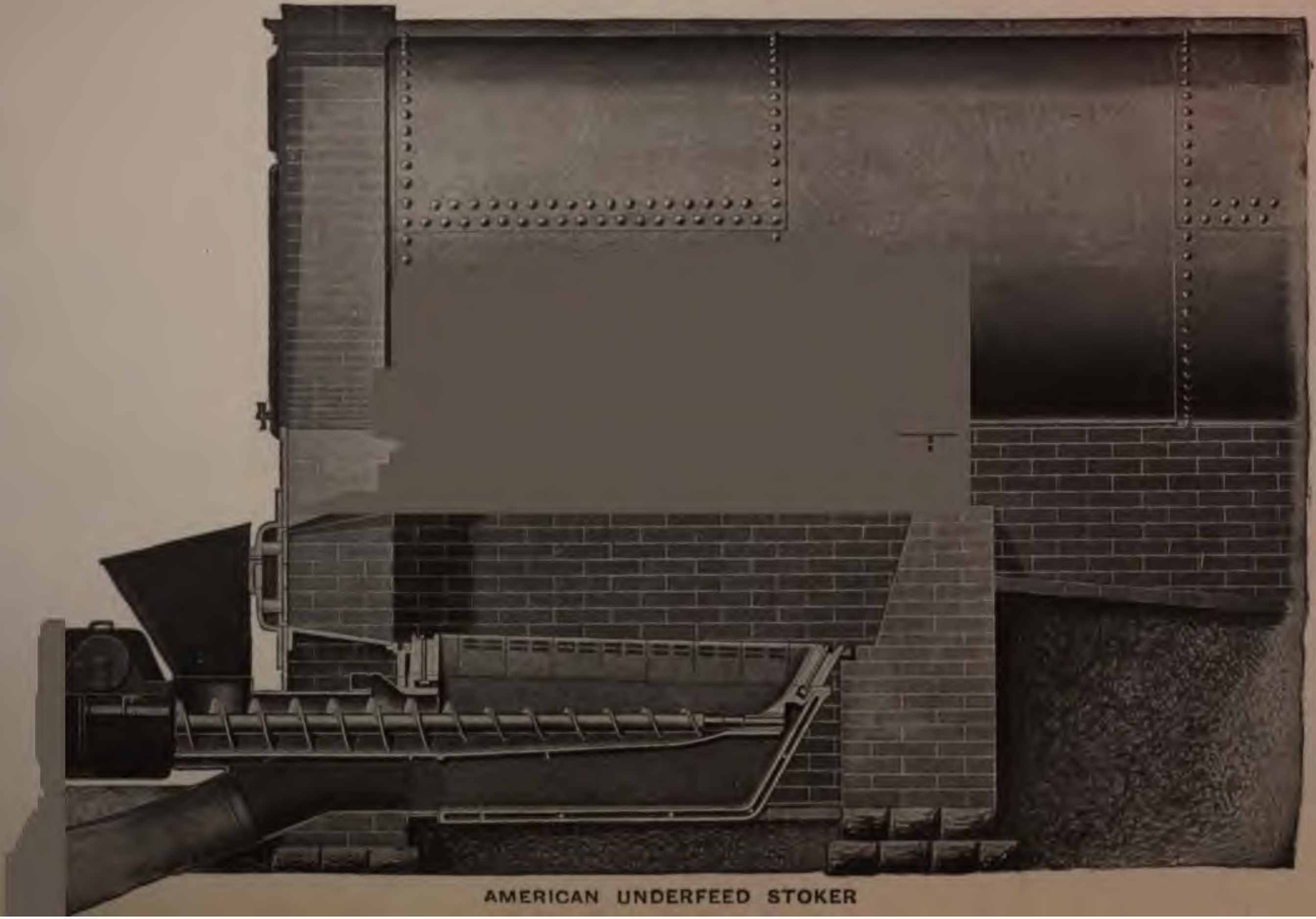

AMERICAN UNDERFEED STOKER

substances. This is the reason for oxidation, rust and the decay of so many substances. Combustion is another example, but in this instance the oxygen does not unite except when the substances are heated. Thus, a building is surrounded and saturated, as it were, with oxygen, but it is harmless until heat produces combustion; then the oxygen combines with the other elements.

Oxygen is called a supporter of combustion. In fact, diamonds, iron and other substances, not ordinarily considered combustible, will burn brilliantly in pure oxygen gas.

At usual temperatures, oxygen combines slowly. If a piece of iron is made bright and then dipped in water, it becomes rusted in a few days; or if a piece of lead is filed until it is bright, it becomes covered with a dull colored coating of oxide of lead.

If air were undiluted oxygen, all animal life would be rapid. If a fire was started, it could be extinguished with difficulty.

Compounds.—As has been stated, oxygen combines with almost all of the elements. These compounds are called oxides.

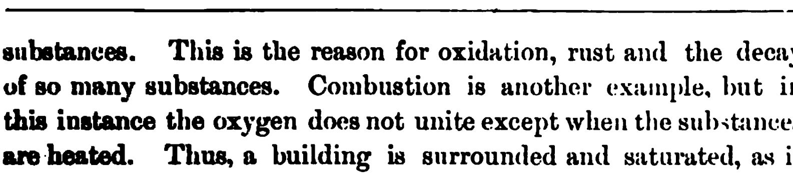

Fig. 3.

The most important of these is water. The compounds of oxygen which are the most important to the engineer, are water and the products of combustion. Oxygen is an important constituent of air, but air is a mixture and not a chemical compound. These substances, water, air and the products of combustion will be discussed later.

Uses.—The principal use of oxygen in nature is to sustain life. It also supports combustion. It is used in the oxy-hydrogen blow-pipe, and in the production of the calcium light.

The oxy-hydrogen blow-pipe consists of two concentric tubes, the inner one conveying oxygen and the outer hydrogen, as shown in Fig. 3. The gases come together at the end and are burned. The flame is almost colorless and has but little luminous power.

Its heat is, however, intense; the temperature being about 2000° F. This intense heat is made use of in melting and refining ores and alloys.

The calcium or lime light is made by directing the flame from the oxy-hydrogen blow-pipe upon a block or cylinder of lime. The intense heat produced by the burning of the gases, causes the lime to become white hot, and to give out a brilliant, dazzling light. Illuminating gas can be used in place of hydrogen. The calcium light is used for stereopticons, and for stage effects in theatres. It has been used in carrying on important engineering construction work during the night. At the present time, the electric light is taking the place of the lime light to a great extent.

Preparation. — Oxygen may be prepared in many ways. Priestly prepared it by heating red oxide of mercury. The process is represented by the equation,

$$\begin{aligned} 2HgO &= O_2 + 2Hg. \\ 2\ (200 + 16) &= 32 + (2 \times 200). \\ 432 &= 432. \end{aligned}$$

The most usual method of preparing oxygen is by heating a substance called chlorate of potassium ($KClO_3$). The following formula explains the chemical change,

$$2\ KClO_3\ (\textit{heated}) = 2\ KCl + 3O_2$$

The heat sets free the oxygen and changes the chlorate of potassium to potassium chloride.

This substance, $KClO_3$, breaks up only at a comparatively high temperature and with explosive violence; but by mixing with it a little manganese dioxide (called black oxide of manganese) much less heat is required, and the oxygen evolves slowly and continuously. The manganese dioxide does not appear to take any chemical part in the process, but remains unchanged.

HYDROGEN.

Occurrence. — Hydrogen is rarely found on our globe uncombined or in a free condition. The reason for this is its great affinity for oxygen which is so abundant. In combination, hydrogen is very abundant and widely distributed. Hydrogen is in all water, wherever it may be. Besides water in the form of oceans, lakes, rivers, etc., it is one of the principal elements in animal and vegetable life. Hydrogen is a constituent of natural gas, meteorites, and most acids and bases.

Discovery. — Hydrogen was isolated in 1766 by an English chemist, Cavendish, who called the gas "inflammable air;" but Lavoisier named it *hydrogen* which means "*water former.*"

Cavendish was a very eccentric individual, having scientific pursuits the object of his life. His silent accurate work did much toward the progress of the science of Chemistry.

Physical Properties. Hydrogen is the lightest of gases, being only $\frac{1}{16}$ as heavy as oxygen. When pure it is colorless, odorless and tasteless. It is but slightly soluble in water. On account of its lightness it was formerly used for inflating balloons, but as hydrogen is expensive, illuminating gas is now used, although it is much heavier than hydrogen.

Hydrogen has been liquefied at—238° C and under a pressure of 300 pounds per sq. in. Also it has been solidified by Dewar.

Chemical Properties. — The most interesting and most striking property of hydrogen is its power to unite with oxygen. When oxygen and hydrogen unite, heat, light and flame appear, and a new chemical compound is produced. These are the phenomena of combustion.

Hydrogen will not unite with most metals. For a few elements, it has great attraction. Hydrogen combines with boiling sulphur, and has a strong affinity for chlorine, forming hydrochloric acid, HCl.

Under ordinary conditions, hydrogen will not combine with carbon, but there are hundreds of compounds of hydrogen and carbon, called hydrocarbons, CH_4, C_2H_6, etc.

Hydrogen burns in oxygen or in the air with a blue, almost colorless flame, of great heat. One pound of hydrogen will give out more heat in burning, than will a pound of any other substance.

As to its being a substitute for air, hydrogen in this respect differs radically from oxygen. Hydrogen will not support animal life, neither will it support combustion. An animal placed in a room filled with hydrogen expires almost immediately. If a candle, or a lighted match is placed in a jar of hydrogen, it goes out. The hydrogen seems to deprive the animal or the candle of their necessary oxygen.

Compounds. — Compounds containing hydrogen are exceedingly numerous; water, acids and hydrocarbons being among the most common.

Uses. — As an elementary gas, hydrogen has few uses. Its great lightness made it a desirable substance for balloons, and its great heating power made it invaluable for the oxy-hydrogen blow-pipe. However, on account of the high cost of hydrogen, illuminating gas is now used extensively in the above cases. It is, however, used by the chemist as the unit for density and atomic weight, and as the standard for valence. The great value of hydrogen is in its compounds rather than in an uncombined state.

Preparation. — The chemist can obtain hydrogen in many ways. As water is composed of oxygen and hydrogen, it is only necessary to decompose water into its constituent elements. This is done by means of an electric current.

The most common way to produce hydrogen is by the action of sulphuric acid on zinc. However, hydrochloric acid and other metals beside zinc can be used. The acid should be diluted somewhat, so that it will readily act on the zinc. The chemical change is represented by the following reaction:

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$
$$65 + 98 = 161 + 2$$

In this experiment, zinc has changed places with the hydrogen and the hydrogen is left without anything with which to combine.

Hydrogen thus produced is seldom pure, as the various substances used are likely to contain substances which give some impurity to the gas thus formed.

WATER.

Now that we know something of the elements, oxygen and hydrogen, we can study the most important compound of these two elements.

The chemical history, properties and uses of water are both interesting and important, and if treated with any degree of thoroughness would furnish material for a volume.

Water is very abundant; it is necessary to both animal and plant life, and is extremely useful to man.

As to its abundance, one has but to look out upon the ocean from a high cliff to become convinced of the enormous quantity.

The oceans cover over three-fourths of the surface of the earth, and their depths may be measured in miles. Besides the ocean, there are numerous lakes, rivers, canals, &c.

Water is essential both to animals and plants. If water were banished from the earth, all animals would die almost instantly, and the vegetables would soon cease to grow. The blood which courses through our bodies is about seven-eighths water. The human body itself is more than half water. Vegetables, which form such a large part of the food of animals, are made up largely of water. Cucumbers contain about 97 per cent. water, and it is said that some forms of jelly-fish have been found to contain 99.9 per cent. of water.

Besides being necessary to the existence of man, water aids him in many ways. The oceans, rivers and lakes are the great highways upon which man carries on commerce. Many factories are run by water-power. But to the engineer, water, as water and steam, is of great importance. In most cases, it is the steam engine that furnishes power directly, or develops it to be transmitted by electricity or by compressed air.

Properties. — Water exists in three states, solid, liquid and gaseous. At ordinary temperature (60° F.) it is a liquid. As it is cooled it contracts slightly, until it reaches 39.2° F. expanding slightly thence to the freezing point 32° F. This property is of great value; when water freezes it expands, and as it then occupies a greater volume it becomes relatively lighter. On this account, ice rises to the surface of a lake and stays there forming a covering which prevents the water from becoming uninhabitable for fish. The same property prevents a lake from becoming a solid mass of ice which could not be melted by the summer sun. The expansion at the moment of solidification also causes the water in the crevices of rocks and in the soil to break up the rocks and prevent the surface of the soil from becoming hard.

Let us consider what effect water has on the climate. The heat of the sun in the tropics changes water into vapor; this vapor is carried by the winds to the colder portions of the earth where it is condensed and falls as rain or snow. In order to turn water into vapor, heat must be applied and stored up in the vapor.

When the vapor is condensed into water, heat is given out by the vapor. This process makes the tropics cooler, because heat is taken from the atmosphere and absorbed by the vapor, and makes the cold portions of the globe warmer because heat is evolved.

Thus the circulation of vapor is like a steam heating plant. The boilers are at the tropics, and the condensers, or radiators, are all over the globe. The sun's rays make the steam. This apparatus has the same principle as a boiler, but it works without tubes, shell or radiators.

There is another way that water tends to regulate the climate. In the hot days of summer, the water of a lake or the ocean becomes warmer. However, it takes more heat to raise the temperature of water one degree than it does to raise the land one degree. Thus, the water will absorb a large amount of heat without having its temperature raised to the extent that might be expected. In hot weather, heat is absorbed by the water, but its temperature is not very high, and as its temperature is low, it has a tendency to cool the surrounding land. Now in cold weather, the store of heat in the water is given out as the water cools. We may say that the ocean or a large lake, is a great reservoir, storing up the heat of summer, and giving it out in winter. This is the reason why the temperature near the ocean is not subject to as great variations as is that of the country far inland.

We know that water is formed of oxygen and hydrogen. This is true, but water as it is found on the earth is never absolutely pure. The fact that so many substances readily dissolve in water accounts for the numerous impurities. As rain falls from the clouds, it absorbs gases and solids. When it flows as a river, it dissolves small quantities of the substances with which it comes in contact.

There are two kinds of impurities, organic and inorganic. Organic matter usually tinges water yellow. Salts in spring waters are taken from the rocks and soil through which the water flowed.

Hard Water.— If water contains lime salts or magnesium salts in solution, it is called hard water. The reason why it is called hard is because of its action on soap. Soft water forms a lather and cleanses the skin, but hard water does not form a lather; the soap combines with the salts to form insoluble lime or magnesium compounds that appear as a scum on the surface. If water contains calcium bi-carbonate, $CaH_2(CO_3)_2$, the CO_2, may be expelled by boiling. The calcium carbonate, $CaCO_3$ is precipitated and appears as a crust or scale. If the water contains calcium sulphate, $CaSO_4$ it may be softened by means of sodium carbonate, Na_2CO_3.

Distillation. Water may be purified by distillation. This process consists in heating water to steam and then condensing the steam. Since most of the impurities are less volatile than water, the salts in the solution are left behind making the condensed steam, pure water. The apparatus used in distilling water is called a still and consists of a vessel for heating and vaporizing the water (called a retort) and a curved tube (called the coil or worm) for cooling the steam. The worm is surrounded by cold water. In Fig. 4 steam enters at A and when condensed flows out at B. The cooling water enters at C and flows out at D.

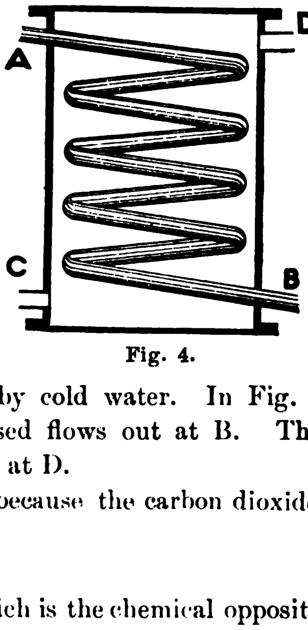

Fig. 4.

Distilled water has a flat taste because the carbon dioxide and air have been expelled.

NITROGEN.

Occurrence.—Nitrogen is a gas which is the chemical opposite of oxygen. Nitrogen exists in the air, and in a few compounds. It occurs free in the atmosphere, of which it is about 77 per cent. of the volume. The most common compounds containing nitrogen are the nitrates; potassium nitrate (KNO_3), and sodium nitrate ($NaNO_3$). Ammonium compounds, such as ammonium chloride (NH_4Cl), are also common.

Organic matter, both vegetable and animal, contains compounds of nitrogen.

Discovery.—Nitrogen was discovered or rather recognized as a constituent of air about the time when Cavendish, Priestly, Scheele, Lavoisier and other noted chemists were making such wonderful discoveries. At this time Rutherford showed that after animals have breathed in a certain volume of air, an inert gas is left behind.

Lavoisier named the gas azote, but Chaptal named it ***nitrogen***, because of its existence in nitre, KNO_3.

Physical Properties.— Nitrogen, if pure, is a colorless, tasteless and odorless gas. It is a little lighter than air. By means of intense cold and great pressure, this gas, like others, has been liquified.

Chemical Properties.— The most striking property of nitrogen is extreme inactivity. It is very inert. It does not burn nor does it support combustion. It is not poisonous, but it gives no aid in supporting life. At high temperatures, nitrogen unites with some elements, but at ordinary temperatures it does not enter into chemical union with other substances.

Although inertness is the marked characteristic of nitrogen, yet this element is a constituent of many compounds which are active to a high degree. Among these are such explosives as gunpowder, nitro-glycerine and dynamite.

Compounds.— Many important compounds contain nitrogen. In nature, nitrogen is necessary to both animal and plant life. It is an important element of muscular fibre and of brain material. It is a constituent of ammonia gas, NH_3, and of a large number of compounds derived from it, which are so essential to plants.

Ammonia.—NH_3 is the principal compound of nitrogen and hydrogen. It is a colorless gas, having a very pungent odor and acrid taste. It is very soluble in water. Ammonia can be liquified and solidified by cold and pressure. Upon evaporating, ammonia absorbs heat, thus producing cold sufficient to freeze water. This property is made use of in refrigerating machines.

Ammonia and hydrochloric acid form ammonic chloride, NH_4Cl, a salt called sal ammoniac,

$$NH_3 + HCl = NH_4Cl.$$

With hydrogen and oxygen, nitrogen forms nitric acid. HNO_3, one of the three most important acids.

Uses.— The principal use of nitrogen is to dilute the active oxygen in the air and make the mixture suitable for breathing. Also on account of the dilution of the oxygen, the nitrogen prevents oxygen from having too rapid action in combustion. The uses of this gas in animal and plant life have been mentioned. Nitrogen unites with oxygen and forms several oxides, one of which, N_2O, is called laughing gas.

Preparation.—Nitrogen may be prepared from air by separating the other constituents from it. As oxygen is the other principal element, it may be burned out by means of phosphorus. As the air is confined in a jar, the burning phosphorus withdraws the oxygen leaving nitrogen. The union of oxygen and phosphorus may be expressed by the equation,

$$2P + 5O = P_2O_5.$$

The P_2O_5 is dissolved in water leaving nitrogen.

Nitrogen may also be separated from oxygen by passing dry air over red-hot copper confined in a tube.

$$Cu + O = CuO.$$

THE ATMOSPHERE.

The atmosphere, or air, which surrounds our globe is a vast ocean of gases. Human beings and other land animals dwell at the bottom of this ocean. The height to which the air extends is not known exactly. Formerly, it was supposed to extend about 50 miles from the surface of the earth; but at the present time some people think it extends to other planets.

Experiment shows that the density of air diminishes rapidly as one ascends. It has been calculated that at the height of about 40 miles the air is as rare as in the so-called vacuum of a good air pump. This calculation seems to show that if the atmosphere extends to the other planets, it must be exceedingly rare.

The ancients thought there were four elements, *earth*, *air*, *fire* and *water*. They called any gas air in the same way that any thin liquid was water. Until Priestly discovered oxygen, air was considered an element. Lavoisier was the first to make an analysis of the atmosphere.

Constituents.—There are five principal constituents of air. These are nitrogen, oxygen, argon, water (as a vapor) and carbon dioxide. Besides these, there are a great many other less important gases. Nitrogen, oxygen, and argon are called the permanent constituents, because their proportion is very nearly constant. The amount of water is very variable. Winds from deserts contain but little moisture; during the rainy season the atmosphere is almost constantly at the dew-point.

Suppose the air contains a certain amount of moisture. Now as the temperature of the air is lowered, a temperature will at length be reached at which the air will be just saturated with moisture. Further reduction of temperature will cause a part of this moisture to be precipitated. The temperature at which the air is just saturated is the dew point for the air under consideration. The dew point varies with the amount of moisture in the air.

Carbon dioxide, CO_2, forms 3 or 4 parts in 10,000 of the atmosphere. In the air above cities, in theatres, and in crowded rooms, the percentage is much larger. Although the percentage of CO_2 is small, yet the total quantity in the air is great.

Of the permanent constituents, nitrogen (the inert gas) forms about four-fifths of the whole; oxygen (the active element) forms about one-fifth, and argon nearly one per cent.

Argon is a comparatively new element, being discovered in 1894. It was found that when nitrogen was obtained from the atmosphere it was $\frac{1}{2}$ per cent. heavier than when made from chemical compounds. This fact lead to its discovery. Argon is of little importance. Its resemblance to nitrogen accounts for the late discovery. It is the most inert of all known substances, and combines chemically with no elements. It is more soluble in water than nitrogen, and has been liquified at —121° under a pressure of about 750 pounds per square inch. It freezes at —191°.

Besides the large number of gases found in the atmosphere, there are minute quantities of solid materials of many kinds. For instance, common salt is blown up into the atmosphere from the waves of the ocean and carried far inland.

The atmospheric ocean is like the liquid ocean in one respect. While rivers flow to the ocean, they carry along pulverized rock, vegetable matter, impure products from manufacturing establishments and washings from the soil. All these impurities find their way to the ocean. In the case of air, all living animals pour out with every breath from the lungs, waste materials from their bodies. Wherever fuel is burned or wherever a manufacturing plant allows the escape of gases or vapors or pulverized solids, these are mingled with the atmosphere. Thus the air is a great reservoir, in which are found almost all gaseous substances.

The various constituents of air exert various influences upon it. The oxygen is the active constituent; it is the portion necessary to the existence of animals and combustion.

The chief duty of the nitrogen is to dilute the oxygen and weaken its excessive activities. Let us consider what would happen if the air were made up entirely of oxygen. It has already been said that iron and other metals burn in pure oxygen. Then if the air were pure oxygen, the heat in stoves would cause the iron to burn and the result would be that there would be no restraining the conflagation. The influence of argon is practically the same as that of nitrogen which it so strongly resembles.

The moisture in the air is of great value to animal and plant life. We know that water has a great capacity for retaining heat. When the sun's rays penetrate the atmosphere, some of the heat is absorbed by the earth and then imparted to the air above it. The moisture in the air hinders the escape of this heat. The heat thus imprisoned, as it were, greatly aids the growth of animals and plants. The earth imparts heat only to the layer of air immediately above it, as is shown by ascending a mountain; the vegetation may be luxuriant at the base, but as the mountain is ascended, the richness of vegetation diminishes and a height is soon reached where perpetual cold and snow prevail; no animals exist and only the lowest forms of vegetation can be found.

The glories of the sunrise and sunset are due to moisture in the air. The light shining through the drops of water that float about in the form of clouds, produces the beautiful effects.

Carbon dioxide, the fifth important constituent of air, is formed as has already been stated, when combustion takes place either in a fire or in animals. When an animal breathes, minute particles of animal tissue are burned, and one of the products of this combustion is carbon dioxide. For this reason, the animal body has been likened to a furnace.

On account of the large number of animals on the globe, and the immense quantity of coal that is burned, one might think that the carbon dioxide by continually increasing would soon form a large proportion of the atmosphere. Nature has wonderfully provided for this. The carbon dioxide, which is the waste matter of animals, is one of the foods for plants. Thus the trees of the forest are continually taking in the carbon dioxide and giving out pure oxygen, which is at the same time the refuse of plants, and the life giving oxygen which animals demand.

CHEMISTRY OF AIR.

On account of the abundance and importance of air, it has been studied with great care. It has been carefully analyzed. Experiment shows that air seems to be a chemical compound by reason of one fact — the two principal constituents, oxygen and nitrogen, have been found to exist in almost constant proportions. Every other consideration, however, seems to show that air is a mechanical mixture.

If air were a chemical compound, the proportions of the constituents would not vary, but the amount of oxygen is found to vary from 20.908 to 20.999 per cent.

Among other reasons for thinking air a mixture, is the following: Suppose air were composed of exactly 20 per cent. oxygen and 80 per cent. nitrogen, then the symbol would be N_4O. If four volumes of nitrogen are mixed with one volume of oxygen, the mixture behaves like atmospheric air. When the gases are brought together, no heat is either liberated or absorbed; also there is no condensation. These phenomena are observable in the case of chemical union. An investigation of the vapor density, also shows the air to be a mixture, and not a chemical compound.

CARBON.

Occurrence. — Carbon exists in nature in many forms. It is seldom found pure or uncombined, although many substances are made up largely of carbon. Carbon exists in three distinct forms; **amorphous carbon, graphite and diamond.** Amorphous means not crystalline. Graphite and diamond are the crystalline forms. Although these three forms bear no resemblance to one another, and their properties differ considerably, yet they are all varieties of the same element.

Discovery. — Carbon, as charcoal, was thought by the phlogistonists to be very pure phlogiston, because it burned leaving but little residue. Graphite was known to the alchemists; pencils were made of it in the sixteenth century. In 1772, Lavoisier burned a diamond, thus proving that it was not quartz. In 1796, equal weights of diamond, graphite and charcoal were burned, giving equal weights of carbon dioxide, CO_2. This proved that all these three substances were forms of carbon.

AMORPHOUS CARBON.

Amorphous carbon exists as charcoal, bone-coal, lamp-black, coke, gas carbon and mineral coal. Of these, mineral coal is found in the earth, the other forms being artificial products.

Charcoal is probably the most familiar form of carbon. Charcoal is not pure carbon, as it contains minerals and other impurities. It is made by heating wood without burning it, or only partially burning it. By heating wood for a time out of contact with air, the compounds which form the fiber are broken up and the gases driven off or burned. This process is called distillation, and as the compounds are destroyed, it is sometimes called destructive distillation.

Charcoal is usually prepared by piling wood in a conical heap as shown in Fig. 5, covering it with sods and earth and letting it smoulder. Small openings are left for air. For this process a portion of the wood is burned and the rest only charred. The heat decomposes the wood, expelling the volatile gases. The product is a solid which consists mainly of charcoal.

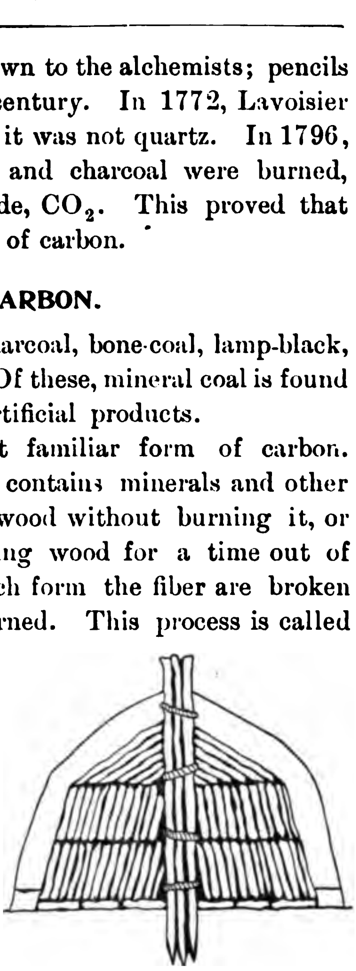

Fig. 5.

Charcoal is a black, amorphous, porous substance, having neither taste nor odor. It is insoluble in any liquid, and cannot be melted or vaporized except in the electric furnace.

Animal charcoal is made by treating in a similar manner animal matter such as waste leather. When bones are burned, the volatile portions (water, ammonia etc.) are driven off, and the carbon is left deposited on calcium phosphate. This product is called **bone-black,** and is used in refining sugar.

Lamp-black is a nearly pure form of uncrystallized carbon. It is made by partially burning turpentine, oil, tar, resin etc., and collecting the unburned carbon or smoke.

The smoke flows into a chamber, as shown in Fig 6, where the sooty material collects on the walls and floor. It is scraped off and sold. Lamp-black is used in printers' ink, black paint, etc.

Coke is formed from soft coal. The coal is distilled upon the same principle as in wood. The process drives out the volatile gases, which are used for illuminating. Like charcoal it is very porous, but requires a high temperature to set it on fire. Coke is used for heating.

Gas Carbon is formed in the manufacture of coke and illuminating gas. It is very dense and hard.

Mineral Coal is a well-known compound of carbon. It is very abundant, being found in almost every country in the world. The United States has by far the largest amount.

Coal was once wood. It is the accumulated masses of the remains of a luxuriant vegetation of an early period of the history of our globe. Many centuries ago the earth contained vegetable life which was at least as rank as it is to-day. The earth's crust has been subject to upheaval and subsidence, which have caused the various layers to be contorted. Plant life was buried, and as time went on, it became covered with earthy matter, thus being subjected to pressure and also to a slow distillation by heat. This action of heat, pressure and percolating waters, changed the wood to coal.

Coal is found in two distinct varieties: Anthracite or hard coal, and Bituminous or soft coal.

Anthracite is rich in carbon, some varieties having about 90 per cent. It seems to have been formed from soft coal, under conditions of pressure and temperature which expelled the more volatile constituents. As anthracite coal has had most of it volatile gases expelled, it burns with little flame and will ignit only at a high temperature. It is used for heating houses, but is more expensive than soft coal, and far less abundant.

Bituminous Coal has several sub-varieties, Cannel a Lignite. They are not as pure forms of carbon as bitumin coal. Peat is a low form of lignite or brown coal. Bitumin coal contains less carbon than hard coal, but is richer in hydrocarbons. It gives off considerable smoke and burns with much flame at a lower temperature than anthracite, On account of the volatile gases, it is much used for making illuminating gas and coke. Cannel coal is very rich in hydrocarbons, but is very expensive.

GRAPHITE.

Graphite, also called black-lead, plumbago, etc., is a compact and comparatively pure form of carbon. It is quite abundant and widely distributed. It is found in some places as a continuation of beds of anthracite coal which thus indicates its origin. Like coal, graphite seems to come from plant life.

Graphite is a soft, black crystalline mineral, insoluble in any substance at ordinary temperatures, and is almost infusible. Graphite is a good lubricant. It is practically infusible and unlike other forms of carbon can be burned only at the highest temperatures when it forms carbon dioxide, CO_2.

Carbon, as a graphite, is very useful. It is used as a lubricant, for facing molds for iron castings, for electrotype facings, lead pencils, stove polish and polish for gunpowder. On account of its infusibility and incombustibility, it is used for lining crucibles in which iron and steel are melted. Coal and graphite are of precisely the same chemical nature, yet while coal is burning in the fire, and thus furnishing intense heat for melting metals, the graphite, of which the crucible is made, resists heat and combustion and while allowing the metals to melt preserves them.

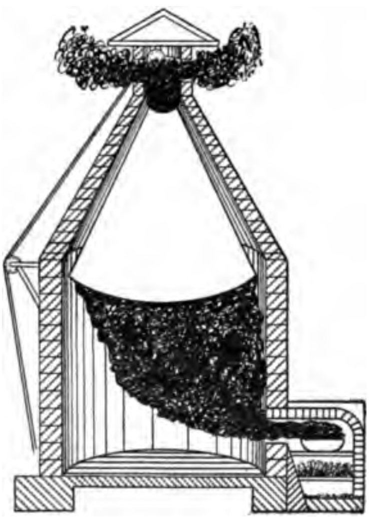

Fig. 6.

DIAMOND.

The diamond is nearly pure carbon crystallized. It is one of the most wonderful substances known. Diamonds are found in only a few places on the earth, and are not abundant. Since the time of the ancient Greeks and Romans, the diamond has been prized on account of its brilliancy, rareness, hardness and unchangeability. The largest diamond ever found weighed less than half a pound, and is valued at over half a million dollars. Diamonds are cut in exact geometrical shapes as shown in Fig. 7, by splitting off portions. They are then polished by rubbing them on a revolving plate upon which is a mixture of oil and diamond dust.

Diamond is the hardest substance known with the possible exception of the artificial product, boron. There have been many attempts to make diamonds by melting carbon and then letting it crystallize. By fusing carbon with iron, minute crystals have been produced.

The principal use of diamonds is as a precious stone. Because of its hardness, it is used for cutting glass, and poor varities are used in rock drills.

OTHER FORMS OF CARBON.

In addition to the three forms of carbon already briefly described, it exists in many compounds with other elements. It is found in the atmosphere in carbon dioxide gas. Also, it is one of the important constituents of petroleum. Marble and limestone contain enormous quantities of carbon. These minerals consist largely of calcic carbonate, $CaCO_3$. Almost all animal and vegetable matter contains carbon.

USES.

The uses of carbon in the form of charcoal, graphite and diamond have already been mentioned; but some of the more important uses are worthy of discussion. On account of the infusibility, carbon is used in the pencils of arc lights. It slowly burns away, but this is expected as the current flowing from one pencil to the other gives out intense heat as well as brilliant light.

Carbon, whether as wood, charcoal or bone-black, has a wonderful power of decolorizing liquids. When colored solutions are strained through a quantity of one of these forms of carbon, the carbon absorbs the coloring matter, and the liquid that has passed through is practically colorless. On account of this property, enormous quantities of bone-black are used for whitening syrups before they are crystallized to sugar.

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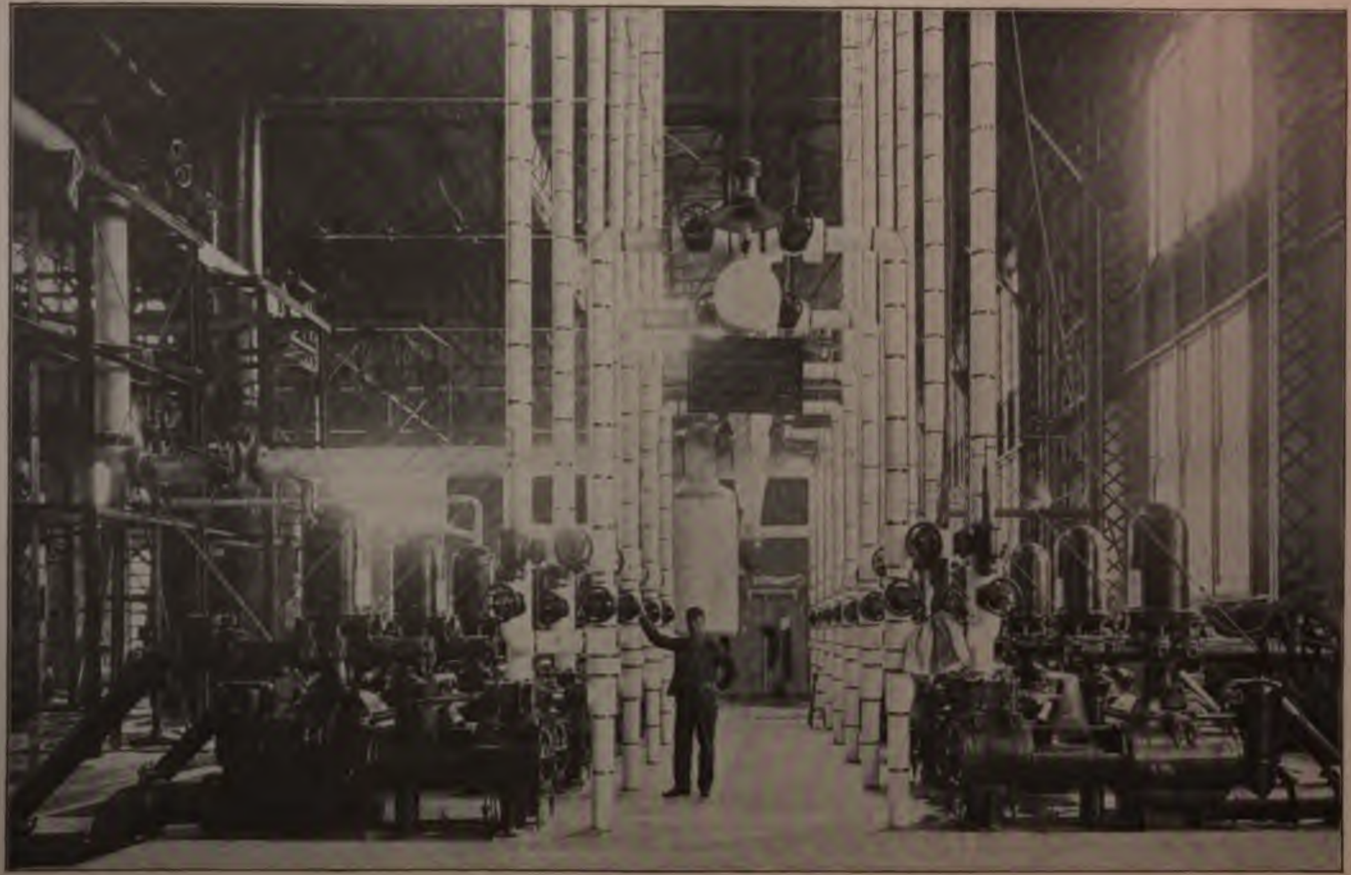


BOILERS AND CONNECTIONS, ST. LOUIS EXPOSITION.

A similar property to this, is the power that charcoal has of absorbing offensive gases. Hence, it is used as a disinfectant. If tainted meat is packed in freshly burned charcoal, it soon loses its odor.

COMPOUNDS.

There is a large number of compounds of carbon. The reason why the number is so great is that the valence of carbon is four. We saw that the valence of hydrogen is one, and that of oxygen is two, and that there are few compounds of these two elements. Now as carbon has four hooks with which to take hold of other substances, it naturally takes hold of a great many.

Although carbon is very inert at low temperatures, yet at high temperatures, carbon draws oxygen away from almost all known elements. It thus shows that its chemical force is superior to that possessed by any of them.

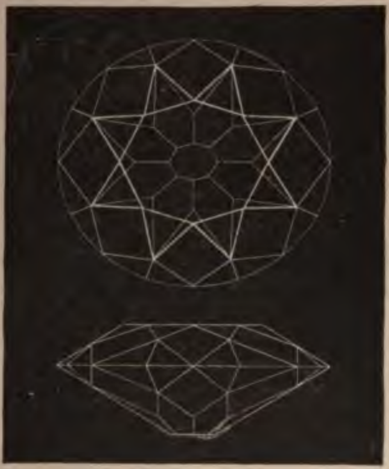


Fig. 7.

Carbon unites with oxygen forming carbon monoxide, CO, and carbon dioxide CO_2. These interesting and important compounds will be discussed with the subject Combustion, with which they are so intimately connected.

With other elements carbon forms many useful and important compounds. Many of these compounds belong to that branch of science called Organic Chemistry. Organic Chemistry was formerly considered as the chemistry of substances derived from existences that possess organs such as animals and plants. At present, however, it is considered to be the chemistry of carbon and its compounds.

This subject is of such an extent that it is impossible to discuss it here. The simple fact that organic compounds include vegetable juices, extracts, gums, resins, essences, acids, oils, alcohols, coloring matter and many others is an indication of the extent and importance of this branch.

Most of the substances thus named are compounds of hydrogen and carbon, or of carbon, hydrogen and oxygen.

ILLUMINATING GAS.

Illuminating gas is made by two methods. If made from carbon and water, it is called *water gas;* if made by the destructive distillation of bituminous coal, it is called *coal gas.*

Water Gas.— This gas is extensively used at the present time in large cities. The process of manufacture is briefly as follows: Superheated steam is passed through red hot anthracite coal, and the gases thus formed, collected. The chemical combination may be represented by this reaction,

$$H_2O + C = CO + 2H.$$

The coal, which is contained in large cylinders (Fig. 8), is set on fire, the combustion being accelerated by a strong air blast at A. While the coal is thus burning, CO and CO_2 are formed, and the CO_2 passes off through the hood H. When the coal is burning well, or is incandescent, the air blast A is closed, as is also the top of the cylinder at C. The valve E is now opened, and the superheated steam from the boiler enters the cylinder, passes up through the burning coal, and the products CO and H (see reaction) pass out the pipe D to a reservoir. When the steam has cooled the coal, the valve E is closed, and the coal again heated.

As both H and CO burn with a feeble flame, it is necessary to mix with these some substance which will make the gas give more light. The light-giving constituents are usually the hydrocarbons obtained by distilling naphtha or petroleum.

Coal Gas. — To make this gas, cylinders called retorts made of iron or fire clay are filled with soft coal and heated to over 1000° F. by a coal fire. The gases formed pass upward through the exit pipe to the hydraulic main, which is a large pipe through which water is kept flowing. The products of distillation which pass to the hydraulic main are liquid, semi-liquid and solid (hydrogen, carbon dioxide, sulphur, ammonium compounds, coal tar, &c); these are washed and some of them deposited in the main.

The insoluble gases pass to the condensers, which are a series of vertical pipes placed in the open air. As the gas is thus cooled, tarry liquids, which have been in the gas in the form of a vapor, are deposited.

Next the gas flows to the washers, or scrubbers, where it meets a falling spray of water which by absorbing ammonia (NH_3) and hydrogen sulphide H_2S washes the gas. It then goes to the purifiers, which are large iron boxes with a large number of shelves on which is dry quicklime, CaO, or hydrated ferric oxide. The quicklime absorbs H_2S and other acid gases. The gas is now pure enough for use, and passes into the large tanks called gas holders from which it goes to the consumers.

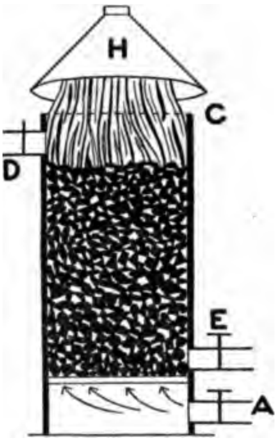


Fig. 8.

Composition. — When coal distilled gas is in its purest condition, it is a very complex substance and the proportions of the constituents vary somewhat. About 5 per cent. is made up of hydrocarbons, such as C_2H_2, C_6H_6, C_2H_4, &c. These hydrocarbons are the light-giving portions. Impurities, such as CO_2 and N make up about 5 per cent. more. The remaining 90 per cent. is made up of three gases which give but little light. These are H about 45 per cent., CH_4 about 40 per cent., and CO about 5 per cent.

Products. — There are three distinct classes of products of the distillation of coal; solids, liquids and gases. The solids are left in the retorts, the liquids are condensed in the coolers, and the gases are absorbed by quicklime and water, and pass to the gas-holder.

The **solids** are coke and gas carbon. Coke, the spongy substance left in the retort, is a form of carbon. It is used as a fuel. The **gas carbon** is a sort of scale, and is used for the carbons for electric lights.

The **liquids** consist of complicated mixtures of carbon compounds, but they are of great interest and importance. When coal gas was first made, these liquid products were thrown away, but little by little chemists began to recognize their value, and now they are very useful in the arts. From the filthy and offensive coal-tar, the most beautiful and brilliant dye-stuffs are made. These dyes are very permanent. One of the substances from coal-tar is benzole, a compound C_6H_6, from which the well-known aniline dyes are produced. The preparation of these dyes from the apparently worthless product, coal-tar, is a great achievement.

The gaseous products. — The gases generated in the process of coal-gas manufacture are numerous. Some are combustible, but have little illuminating power, such as hydrogen and carbon monoxide. Others, ethylene (C_2H_4), for instance, have high illuminating power. Nitrogen is always formed, but contributes nothing to the value of the gas. The sulphur compounds, H_2S, etc., burn, but form undesirable oxides of sulphur.

COMBUSTION.

Combustion is a rapid chemical combination of the substance that burns, and the substance that supports combustion. It is usually attended with light, and always with heat.

The two principal substances that burn are carbon and hydrogen, or their compounds; the supporter of combustion is oxygen. In addition to the two substances (the one that burns and the supporter), another condition is necessary — a temperature sufficiently high for the union of the substances.

If a stove is partly filled with wood or coal (both contain carbon and hydrogen), and the doors opened, the substances will not burn, although there is plenty of oxygen surrounding the lumps of coal, If, however, the temperature of the coal is raised sufficiently high, the wood or coal burns; or, chemical union takes place.

In order to have carbon, hydrogen or sulphur burn, they must be set on fire or kindled. In other words, the temperature of the substance must be raised to a certain degree before it will burn. This is called the kindling point, and the kindling point varies for different substances.

Flame indicates the combustion of a liquid or gas. Solids simply glow when burning, but do not give out flame.

Coal, the principal fuel used in engineering, is composed chiefly of carbon, the amount varying from about 50 per cent. to 85 per cent. In addition to carbon, coal contains compounds of hydrogen and carbon, called hydrocarbons. These are gases which burn with both light and heat. The third constituent of coal is called ash. It is an earthy substance which remains after the burning of the coal.

As already stated, combustion is a rapid chemical combination of oxygen with carbon and hydrocarbons. Oxygen and carbon have a very strong attraction for each other at high temperatures, and unite with great force, producing light and heat.

When coal is first thrown on the fire or placed on the dead plate, the heat from the fire drives off the hydrocarbons. These gases, being combustible, are burned above the fire or, as in the case of a marine boiler, in the combustion chamber. In order to have the hydrocarbons burn, enough oxygen must be admitted to unite with them, and the temperatnre must be sufficiently high. If these hydrocarbons do not burn, because of low temperature or of insufficient oxygen, they pass up the chimney and a large amount of available heat is lost.

After the hydrocarbons are driven off, the solid portion, coke, is left on the grate or dead plate. To burn the coke, air (containing oxygen) passes up between the grate bars and through the spaces between the pieces of coal.

In burning both hydrocarbons and carbon, or coke, certain new substances are formed, which are called products of combustion. These are gases, carbon dioxide, CO_2, carbon monoxide, CO and water, H_2O (as a vapor).

If there is plenty of oxygen present when hydrocarbons and carbon are burned, the products are CO_2 and H_2O. If there is insufficient oxygen, the products are CO and H_2O.

CARBON DIOXIDE.

This important and interesting gas is called carbon dioxide. carbonic acid, carbonic acid gas and carbonic anhydrid. Its importance and effect on animal and plant life have already been mentioned. The principal natural source in the atmosphere is the combustion of fuel. The gas is made up of carbon and oxygen, and as coal, wood, oil, illuminating gas, etc., are all carbonaceous substances this gas is formed whenever combustion takes place.

Carbon dioxide occurs combined in all carbonates; limestone, $CaCO_3$, being the most abundant.

To prepare carbon dioxide it is only necessary to cause some acid, as hydrochloric acid, to act on a carbonate, as calcium carbonate, $CaCO_3$. The gas thus liberated can be collected and used to ascertain its properties. The action of the acid on the carbonate may be expressed as follows:

$$CaCO_3 + 2\ HCl = CaCl_2 + H_2CO_3.$$

The H_2CO_3 (carbonic acid) is very unstable and breaks up almost as soon as formed into CO_2 and H_2O.

$$H_2CO_3 = H_2O + CO_2.$$

Carbon dioxide is formed whenever carbon burns with plenty of oxygen

$$C + 2O = CO_2.$$

Carbon dioxide is a heavy colorless gas with a pungent odor. On account of its weight, it does not mix readily with other gases or the air, but collects in the bottoms of wells and near the floors in rooms. CO_2 does not support combustion, nor is it a supporter of respiration.

Formerly it was thought that carbon dioxide was poisonous, but it is now thought that CO_2 causes death by excluding oxygen. The fact that carbon dioxide is beneficial to the system if taken into the stomach shows that it is not poisonous.

CO_2 is somewhat soluble in water, and when dissolved in water forms with it a weak, unstable acid, H_2CO_3.

The principal uses of carbon dioxide are as follows: It is used in making soda-water and artificial mineral water. Soda-water is simply water in which considerable CO_2 is dissolved; carbon dioxide being soluble in water. It is also used in chemical engines, because it does not support combustion. When H_2SO_4 unites with sodium carbonate Na_2CO_3, carbon dioxide is formed.

$$H_2SO_4 + Na_2CO_3 = H_2CO_3 + Na_2SO_4.$$

The carbonic acid, H_2CO_3, immediately breaks up into H_2O and CO_2.

The action of yeast in bread-raising is a kind of fermentation; the carbon dioxide and alcohol formed cause the dough to raise and make the bread porous.

CARBON MONOXIDE.

Carbon monoxide is not nearly as common as carbon dioxide. The reason is that the compound CO contains only one-half as much oxygen as does CO_2 and as it is only half saturated, it has a great affinity for oxygen. On account of the activity of CO, it readily combines with oxygen and other elements.

This gas, carbon monoxide, does not occur naturally anywhere, except in case of combustion in a limited amount of air. It forms one of the principal constituents of water gas.

Carbonic oxide is a colorless gas without taste and with but little odor. Its chief property is its poisonous nature. It is the deadly constituent of water gas.

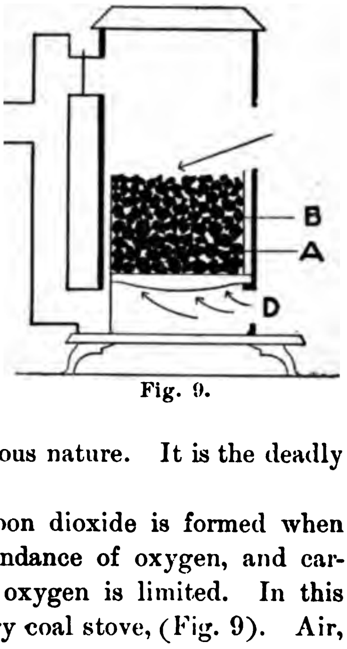


Fig. 9.

As has already been stated, carbon dioxide is formed when combustion is carried on with an abundance of oxygen, and carbon monoxide when the supply of oxygen is limited. In this connection let us consider the ordinary coal stove, (Fig. 9). Air, containing oxygen, enters through the lower door D, and since there is plenty of oxygen, CO_2 is formed in the zone represented at A.

$$C + 2O = CO_2$$

As this carbon dioxide rises through the hot coal, where there is but little oxygen, it gives up one-half of its oxygen to the carbon of the coal, and carbon monoxide is formed in zone B.

$$CO_2 + C = 2CO.$$

When the gas, CO, reaches the surface of the coal, where it meets the oxygen which has entered the draft plate or grid in the upper door, it is changed to CO_2.

$$CO + O = CO_2$$

There is one great difference between carbon dioxide and carbon monoxide that is of importance to the engineer. CO_2 is not combustible while CO can be burned. Let us see how this fact affects the economy of a boiler.

If the air supply is not sufficient to form carbon dioxide, carbon monoxide, CO, is the product. This gas is combustible, and as it will give up considerable heat, if burned, it is undesirable to have it pass unburned up the chimney. This loss is prevented by burning the coal with more oxygen.

We thus see the necessity of admitting sufficient air to the coal, if we wish to run our boiler economically. However, we cannot open the doors and let in an unlimited supply of air, because too much air is a source of loss, as we shall see later. How then are we to know how much air to admit? While the fireman is shovelling coal and regulating the dampers, he cannot stop to figure out the amount of air he should use or is using, but he judges the right amount from the appearance of his fire, and the smoke that issues from the chimney.

By knowing a few principles of chemistry, and the chemical composition of the coal, we can calculate the amount of air theoretically necessary to burn the coal economically.

AMOUNT OF AIR NECESSARY TO BURN FUEL.

Air is composed of about 77 per cent. of nitrogen and argon, and 23 per cent. of oxygen. The oxygen is the only element that aids combustion; therefore, if one pound of air is admitted to the ashpit, only about one-fourth of a pound of oxygen aids combustion; the three-fourths of a pound of nitrogen is inert. The nitrogen is of no aid, but is a source of loss because it must be heated to the same temperature as that of the oxygen. For every pound of air admitted in excess of the amount necessary, three-fourths of a pound of nitrogen takes heat from the coal. Thus we see that the regulation of the air supply is exceedingly important.

If the proper amount of air is admitted, the hydrocarbons and carbon are burned, forming water (in the form of steam) and carbon dioxide. These gases, the products of combustion, together with heated nitrogen and smoke, pass up the chimney.

Carbon Dioxide.

We have already learned that the product obtained by burning carbon in oxygen is carbon dioxide gas, CO_2. This gas is composed of 12 parts carbon and 32 parts oxygen.

$$C = 12, O_2 = 2 \times 16 = 32.$$

Now, since 32 parts are oxygen and 12 parts are carbon, $\frac{32}{12}$ pounds of oxygen are necessary in burning one pound of carbon. In other words, for every pound of carbon that is burned in the furnace, $\frac{32}{12} = 2\frac{2}{3} = 2.67$ pounds of oxygen must be supplied to obtain the product CO_2. Air contains but 23 per cent. of oxygen; then to obtain 2.67 pounds of oxygen from the air, $2.67 \div .23 = 11.6$ pounds must be used.

We have said that 11.6 pounds of air furnishes 2.67 pounds of oxygen. It is evident that the remainder is nitrogen; or $11.6 - 2.67 = 8.93$ pounds of nitrogen are also obtained. Thus if one pound of carbon is burned in 11.6 pounds of air, the products are one pound of carbon, 2.67 pounds of oxygen (making 3.67 pounds of CO_2) and 8.93 pounds of nitrogen.

$$1 \text{ lb. } C + 2.67 \text{ lbs. } O + 8.93 \text{ lbs. } N = 12.6 \text{ lbs.}$$

This is the manner in which the 11.6 pounds of air and 1 pound of carbon unite.

We may say in brief that *to completely burn one pound of carbon we must use 11.6 pounds of air. From this 2.67 pounds of oxygen are used in combustion and 8.93 pounds of nitrogen pass up the chimney without aiding combustion.*

Water.

The product obtained by burning carbon is carbon dioxide; if hydrogen is burned, the product is water, H_2O. We know that water is 2 parts hydrogen and 16 parts oxygen.

$$H = 1, H_2 = 2, O = 16.$$

Then one pound of hydrogen requires $\frac{16}{2} = 8$ pounds of oxygen. To obtain 8 pounds of oxygen, 34.8 pounds of air are necessary, because air contains 23 per cent. oxygen and $8 \div .23 = 34.8$.

If one pound of hydrogen is burned in air, 34.8 pounds of air will be required, and we will get as products 8 pounds of oxygen and 1 pound of hydrogen (making 9 pounds of water) and $34.8 - 8 = 26.8$ pounds of nitrogen.

$$1 \text{ lb. H} + 8 \text{ lbs. O} + 26.8 \text{ lbs. N} = 35.8 \text{ lbs.}$$

To completely burn one pound of hydrogen, we must use 34.8 pounds of air. Of this 8 pounds of oxygen are used in combustion, and 26.8 pounds of nitrogen pass up the chimney without aiding combustion.

Carbon Monoxide.

If the combustion is not complete, the product is CO instead of CO_2. We see that this is so because in equal amounts of CO and CO_2, there is but one-half as much oxygen in the former as in the latter. As there is only one-half as much oxygen in CO as in CO_2, it takes only one-half as much oxygen to burn carbon to CO as it does to CO_2. We know that 11.6 pounds of air are necessary to burn carbon to CO_2; therefore to burn it to CO only $\frac{11.6}{2} = 5.8$ pounds of air are necessary.

If one pound of carbon is burned to CO, 5.8 pounds of air are necessary. Of this 5.8 pounds of air, 1.33 pounds of oxygen are used in combustion, and 4.47 pounds of nitrogen pass up the chimney.

The quantities of air required for combustion are as follows·

To burn one pound of

Carbon to CO_2 requires 11.6 pounds of air.
Carbon to CO requires 5.8 pounds of air.
Hydrogen to H_2O requires 34.8 pounds of air.

Coal is composed of hydrogen, carbon and a small amount of incombustible matter.

From the above we can calculate how much air is theoretically necessary to burn a pound of coal, if we know the amount of carbon and hydrogen in the coal.

Suppose we have a coal composed of the following;

Carbon,	85 per cent.
Hydrogen,	10 per cent.
Ash,	5 per cent.

Since it takes 11.6 pounds of air to burn 1 pound of carbon to CO_2, it would take 11.6×.85=9.86 pounds of air to burn the carbon in 1 pound of coal.

To burn the hydrogen, 3.48 pounds of air are necessary because 34.8 pounds are necessary to burn 1 pound and 34.8×.10=3.48.

Hence, it takes 9.86+3.48=13.34 pounds of air to burn one pound of coal of the above composition.

To find the amount of air theoretically necessary to burn one pound of any fuel, we find the amount required to burn the carbon by multiplying the percentage of carbon by 11.6, and the amount required to burn the hydrogen by multiplying the percentage of hydrogen by 34.8. The sum of these two results is the desired quantity.

EXAMPLE FOR PRACTICE.

A certain kind of coal contains 87 per cent of carbon, 8 per cent of hydrogen, and 5 per cent ash. How many pounds of air will be required to burn one ton (2000 pounds)?

Ans. 25,752 pounds.

METALS.

Such elements as carbon, nitrogen and sulphur when combined with oxygen and hydrogen form acids: carbonic acid H_2CO_3, nitric acid HNO_3, sulphuric acid H_2SO_4. In addition to elements of this class—which we call *non-metals*,—there is a very large and important class of elements called *metals*, with which hydrogen and oxygen form *basic* substances. These basic compounds, such as sodium hydroxide $NaOH$, calcium hydroxide $Ca(OH)_2$ and ferric hydroxide $Fe(OH)_3$, combine readily with acids and destroy the peculiar properties of the acids, at the same time losing their own peculiarities. The new substance thus formed is a *salt;* water is always set free, as shown by the equation:

$$Ca(OH)_2 + H_2SO_4 = CaSO_4 + 2H_2O,$$

in which calcium hydroxide, or slacked lime, is represented as combining with sulphuric acid to form calcium sulphate, which when crystalized with water is called gypsum. This formation of hydroxides, which neutralize acids and thus form salts, is the characteristic chemical property of *metals*.

SODIUM.

This is the most common and important of a group of soft, silvery-white metals, which may be readily cut with a knife, and which rapidly tarnish in air. The other members of the group are lithium, potassium, rubidium and caesium. Of these, potassium alone is sufficiently abundant to be technically important at present.

Occurrence.—Sodium occurs abundantly in nature in the compounds sodium chloride or common salt, and sodium nitrate or Chili saltpetre. Many other compounds of it are found in smaller quantities. Common salt forms immense beds in many parts of the world, and at various depths from the surface of the earth. It constitutes the chief saline matter in sea water, and in the water of such bodies as the Great Salt Lake and the Dead Sea.

Discovery and Preparation.—Sodium was first isolated by Sir Humphry Davy in 1807, by the electrolysis of molten sodium hydroxide, and after a century of experimenting we have returned to this as the best method for its production, due to the reduction in the cost of electric power. In the Castner electrolytic process the sodium hydroxide—or *caustic soda* as it is called—is melted in an iron vessel through the bottom of which passes a negative electrode of graphite. To prevent the oxygen of the air from reaching the sodium, an iron cylinder closed at the upper end is placed over the cathode so that its mouth dips into the liquid electrolyte. The sodium and hydrogen set free at the cathode rise together to the surface. The gas escapes by bubbling out beneath the edge of the cylinder while the metal remains floating upon the fused caustic soda. The outer iron vessel serves as an anode.

Alkalies.—The term alkali, which is applied to the metals of this group, and sometimes also to their hydroxides and carbonates, was originally used to denote the salt obtained by treating the ashes of plants with water. From the ashes of land plants we obtain chiefly carbonate of potassium, which in the crude state is called *potash* from the method of its preparation. The ashes of seaweeds yield chiefly carbonate of sodium.

Properties.—As above stated sodium is a soft white metal, readily moulded by the fingers at ordinary temperatures. It is not affected by perfectly dry air or oxygen. It floats on water, decomposing the water touching it, setting free the hydrogen (which may be ignited), and forming sodium hydroxide which dissolves in the water.

$$2Na + 2H_2O = 2NaOH + H_2$$

The moisture of the atmosphere produces a film of sodium hydroxide which rapidly follows the knife when the bright metallic surface is exposed. By a further step the carbon dioxide in the air changes the surface to sodium carbonate.

Important Compounds.—*With Oxygen:* The only important oxide of sodium is the peroxide Na_2O_2 which is formed by heating sodium to 300°C (572° F.) in dry pure air, or by burning sodium in oxygen. It is a yellowish-white solid which decomposes in contact with water with considerable rise of temperature, and the formation of sodium hydroxide and oxygen.

$$Na_2O_2 + H_2O = 2NaOH + O$$

When slowly added to water or to dilute acids, hydrogen peroxide is formed.

$$Na_2O_2 + 2H_2O = 2NaOH + H_2O_2$$
$$Na_2O_2 + 2HCl = 2NaCl + H_2O_2$$

It is thus a powerful oxidizing agent in either acid or basic solutions, and is used for bleaching.

With Oxygen and Hydrogen.—Sodium hydroxide (Caustic Soda—NaOH). As already stated, this compound is formed when sodium or sodium peroxide comes in contact with water. It is manufactured in large quantities by the action of slaked lime on a boiling solution of sodium carbonate.

$$Na_2CO_3 + Ca(OH)_2 = CaCO_3 + 2NaOH$$

The calcicum carbonate is almost insoluble, while the sodium hydroxide solution is drawn off and evaporated for the market. It is now made quite largely by the electrolysis of brine, the chlorine being collected for the manufacture of bleaching powder, and the sodium acting on the water to form the hydroxide.

$$2NaCl = Na_2 + Cl_2$$
$$Na_2 + 2H_2O = 2NaOH + H_2$$

Sodium hydrate is a white, deliquescent (water absorbing) solid, strongly alkaline and caustic. It is largely used in the manufactures, especially in soap making. The salts of sodium are of great commercial importance, many of them being made in enormous quantities. The starting point for their manufacture is common salt.

Sodium Chloride, or common salt, is dug as rock salt from the great natural beds in Austria, Germany, Spain, Louisiana, New York, and elsewhere. It is also obtained by the evaporation of the water of the ocean or of salt springs and wells, by the heat of the sun or by artificial heat.

Sodium Carbonate, (soda, washing soda, sal-soda) is next to the chloride the most important salt. It occurs in nature in the alkaline beds and waters of Egypt, America, and elsewhere. The ash of sea weeds was the former source of it; now it is manufactured in great quantities by either the Le Blanc process, or the Solvay process, or the electrolytic process. The first was discovered by Le Blanc in France in 1794, and consists of three parts. In the first place common salt is warmed with strong sulphuric acid in a shallow iron pan in a *salt cake* furnace, forming acid sodium sulphate and hydrogen chloride gas.

$$2NaCl + H_2SO_4 = NaHSO_4 + NaCl + HCl$$

The hydrogen chloride passes off and is absorbed by water, forming the hydrochloric acid of commerce. The mixture of sodium hydrogen sulphate and sodium chloride is then raked into another part of the furnace and heated until the remaining hydrogen of the sulphate has been replaced by sodium, forming the *salt cake.*

$$NaHSO_4 + NaCl = Na_2SO_4 + HCl$$

The hydrogen chloride is absorbed as before. Purified salt cake when crystallized is known as Glauber's Salt. The second step is to mix the salt cake with crushed coal and with calcium carbonate in the form of pure lime stone or chalk, and heat the mass in a *black ash* furnace. Here the carbon of the coal reduces the sodium sulphate to sulphide, which is acted on by the calcium carbonate forming calcium sulphide and sodium carbonate.

$$Na_2SO_4 + 2C = Na_2S + 2CO_2$$
$$Na_2S + CaCO_3 = Na_2CO_3 + CaS$$

The product is called Black Ash. This is next leached or lixiviated in tanks with water, the arrangement being such that the nearly saturated water acts on fresh black ash, while the fresh water extracts the last of the sodium carbonate from the nearly exhausted ash. Carbon dioxide is now blown through the liquid to change to the carbonate any sodium hydroxide that may be present. Then in shallow tanks the solution is evaporated to dryness by waste heat from the furnaces, and the crystals calcined and purified. This yields the *calcined purified soda* or soda ash of commerce. If this is dissolved in warm water, the impurities allowed to settle, and the clear solution drawn off and crystallized at the temperature of the atmosphere, we obtain *soda crystals* or *sal-soda* of the formula $Na_2CO_3 \cdot 10\ H_2O$, containing about 60 per cent of water. From this Baking Soda or *sodium bicarbonate*—$NaHCO_3$—can be made by exposing the crystals on a grating to the action of carbon dioxide.

$$CO_2 + Na_2CO_3 \cdot 10\ H_2O = 2NaHCO_3 + 9H_2O$$

The excess of water runs away through the grating. The Ammonia-Soda process or Solvay process was invented by Dyar & Hemming in England in 1838, but did not become a commercial success until after 1863, when the Belgian chemist Solvay constructed an apparatus which, with later improvements, promised to manufacture the greater part of the world's supply of soda. The condition which makes the process possible is that sodium bicarbonate is but slightly soluble in a cold, concentrated solution of ammonium chloride. When therefore carbon dioxide is pumped into the base of a tower, nearly filled with a cold concentrated solution of common salt saturated with ammonia, we have sodium bicarbonate formed as small crystals which gradually sink to the bottom of the tower. It is removed and freed from liquid by centrifugal machines or filter pumps.

$$NaCl + NH_3 + CO_2 + H_2O = NaHCO_3 + NH_4Cl$$

The temperature is kept at 35° C. (95° F.) by the circulation of cold water in pipes. Part of the carbon dioxide is prepared by heating limestone in special limekilns, and the lime thus produced is used for setting free the ammonia from the ammonium chloride, so that it may be used again.

$$CaCO_3 = CaO + CO_2$$

$$2NH_4Cl + CaO = CaCl_2 + H_2O + 2NH_3$$

A large portion of the sodium bicarbonate is calcined to form normal sodium carbonate, and from this action carbon dioxide is also obtained for use in the carbonating tower.

$$2NaHCO_3 \text{ heated} = Na_2CO_3 + H_2O + CO_2$$

The only waste produced is calcium chloride.

Where electricity can be obtained cheaply, the production of sodium hydroxide, as mentioned above, by electrolysis of a solution of common salt, and from it sodium carbonate, promises to become a possible rival to the older methods.

Two classes of apparatus are used. In one the sodium, as set free at the cathode, is absorbed by a liquid metal, mercury or molten lead, and this alloy is presently decomposed by water or steam, yielding sodium hydroxide and hydrogen. In the other form, the chlorine is set free by an anode at the upper surface of the brine and prevented from combining with the caustic soda around the cathode at the bottom by a porous diaphragm of asbestos or similar material. The chlorine is used for making bleaching liquids or powder.

Sodium Nitrate, ($NaNO_3$)—or Chili saltpetre—is found in immense quantities in Chili, mixed with other salts, in the caliche beds. It is purified by solution and crystallization, and exported for the manufacture of nitric acid, potassium nitrate, and fertilizers.

Sodium Phosphate, ($Na_2HPO_4 \cdot 12\ H_2O$) is made by adding sodium carbonate to a solution of calcium phosphate and evaporating. It is a crystalline salt containing over 60 per cent of water.

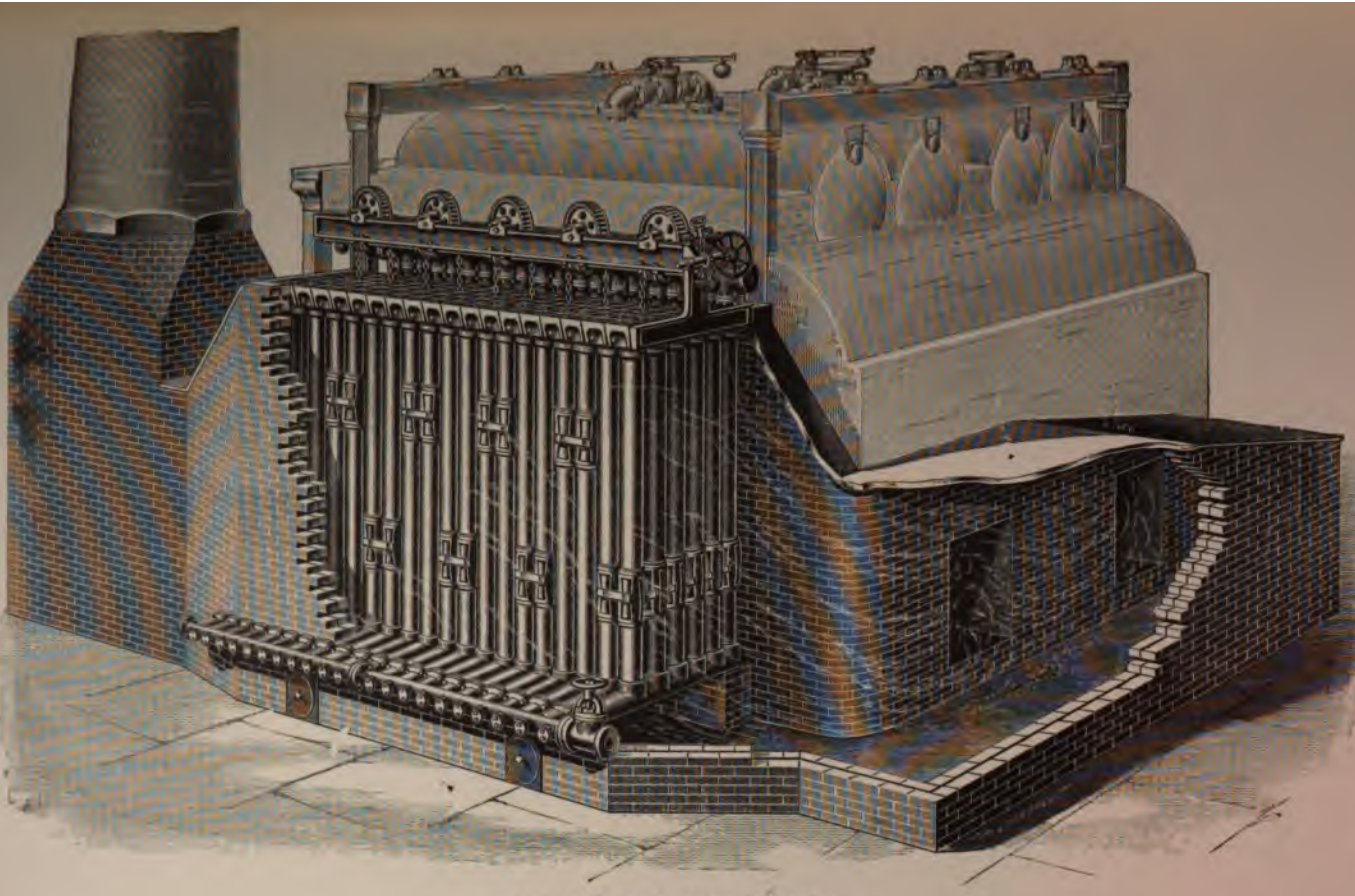
Sodium Thiosulphate, ($Na_2S_2O_3 \cdot 5\ H_2O$) commonly called sodium "hyposulphite," or "hypo," is largely used in photography as a *fixing* agent, to dissolve away the excess of silver salt on a developing plate. It does this by forming a double thiosulphate of silver and sodium, which is soluble in water, and therefore removed by the washing. It is also used to remove excess of bleaching powder from materials bleached with chlorine. In its manufacture caustic soda or sodium sulphite solution is treated with sulphur.

$$Na_2SO_3 + S = Na_2S_2O_3$$

$$6NaOH + 4S = Na_2S_2O_3 + 2Na_2S + 3H_2O$$

CALCIUM.

As sodium may be taken as the type of a group of metals com,



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prising also lithium, potassium, caesium and ribidium, so calcium, in its properties and compounds, is the familiar representative of a group, of which the other members are strontium and barium. Beryllium and magnesium are very closely related to this group, and many of the statements regarding the compounds of calcium are true of magnesium as well.

Occurrence.—Calcium is one of the ten principal constituents of the earth's crust. Carbonate of calcium—$CaCO_3$—is found in particularly large quantities in nature as limestone, marble, chalk, and calcite. Marl, which is used in making Portland Cement, is largely calcium carbonate. Mountain limestone or dolomite, consists of a double carbonate of calcium and magnesium—$CaCO_3 \cdot MgCO_3$. Many of the crystalline minerals, as feldspar and mica, contain calcium silicate. The sulphate occurs in great deposits, as gypsum and alabaster. Calcium phosphate is an important constituent of artificial fertilizers, and occurs as the minerals apatite and phosphorite.

Preparation.—No important use has yet been found for the metal calcium, so that its preparation is of chemical interest only. Its use in place of aluminium is proposed, in steel making, to take out impurities and assist in the production of sound ingots. It can be made by decomposing dry fused calcium iodide with red-hot sodium, and also by electrolyzing the iodide or chloride in a manner similar to that in which sodium is obtained from sodium hydroxide.

Properties.—Calcium is a silvery-white metal, quite soft and malleable, but less so than sodium and potassium. It burns brilliantly when heated in the air, combining with both the oxygen and nitrogen. It decomposes water readily, forming the hydroxide.

Compounds.—Calcium Oxide (CaO) is the common substance quick-lime or unslaked lime. It is made in large quantities by heating calcium carbonate—limestone, marble, oyster shells, etc.—in furnaces called limekilns.

$$CaCO_3 = CaO + CO_2$$

Quicklime melts only at a very high temperature, and when strongly heated glows very brilliantly,—the lime-light. It absorbs moisture and carbon dioxide from the air, and so goes back into calcium carbonate.

$$CaO + H_2O = Ca(OH)_2 \text{ slaked lime.}$$
$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$$

This action is made of great service in construction work. Water is added to quicklime, which combines vigorously with it, forming slaked lime, and setting free considerable heat. This slaked lime is mixed with sand into a paste called *mortar*, which gradually absorbs carbon dioxide, and hardens into a mixture of limestone and sand, binding together bricks or stones into solid walls. The sand prevents the mortar from being squeezed out from between the stones or bricks, and also prevents its shrinking when drying. When heated with clay, quicklime combines with the alumina and silica, and the resulting compounds, when finely pulverized, are the *Portland Cement* of commerce. This material differs from the mortar described above, in that it will *set* or harden under water.

Calcium Hydroxide.—When quicklime comes in contact with water it combines readily with it, at the same time expanding greatly and crumbling to a powder. The heat accompanying this slaking is so great as to occasionally ignite cars or other wooden receptacles containing the lime. Calcium hydroxide is somewhat soluble in water, and the clear solution is the well-known basic liquid—*lime-water*. When exposed to carbon dioxide a film of calcium carbonate is formed on the surface of lime-water, and if the gas be blown through the water, a milky fluid results, due to the particles of calcium carbonate formed. This may be observed by blowing with a small tube through a clear solution of lime-water. The CO_2 of of the breath forms calcium carbonate, $CaCO_3$ which appears as a white cloud. On continued blowing this cloud will begin to disappear, showing that the calcium carbonate at first precipitated is beginning to be dissolved by the CO_2 gas.

Calcium Carbonate.—As noted above this compound forms a considerable portion of the earth's crust, under the names limestone, marble, and chalk. While practically insoluble in pure water, it is dissolved by water containing carbon dioxide. Rain water which absorbs carbon dioxide from the air, therefore dissolves calcium carbonate quite appreciably, one result being the formation of caves of greater or less extent in limestone countries. The waters of springs, wells, rivers and lakes, for the same reason, contain dissolved in them, usually several grains of limestone per gallon. When such water is heated the carbon dioxide dissolved in it is expelled, and the limestone being no longer soluble is precipitated, resulting in the formation of the *scale* found in tea-kettles and boilers. To steam users this is a serious evil, as a lining of one-fourth of an inch of scale in a boiler, necessitates the use of about 30 per cent more fuel, to obtain similar quantities of steam.

When soap is added to water in which salts of the heavy metals—calcium, iron, zinc, magnesium, etc.—are dissolved, the soap will form little if any lather at first, but instead forms an insoluble, curdy material, which is really a soap containing the calcium, or other metal. Such water is known as *hard* water, in contrast with rain or other waters which at once form lather with soap. As salts of calcium, especially the carbonate and sulphate, are by far the most common in natural water, the attempts to soften water are usually aimed at these substances. We have seen that the solubility of calcium carbonate depends on the presence of carbon dioxide, and that the expulsion of this gas by heat results in the precipitation of the carbonate. One efficient way of preventing the formation of scale in a limestone country, is therefore the use of feed-water heaters. Lime water in proper quantity added to boiler-feed water in tanks, will combine with the carbon dioxide in the water, and so cause the precipitation of the carbonate.

$$CaCO_3 \cdot CO_2 + Ca(OH)_2 = CaCO_3 + CaCO_3 + H_2O$$

Waters containing calcium carbonate or magnesium carbonate in solution are known as *temporarily hard* waters, because they can be softened by boiling as above indicated. Other salts, which cannot be so readily removed, make water *permanently hard.*

Calcium chloride.—($CaCl_2$.) This salt is formed when calcium oxide or hydroxide or carbonate is dissolved in hydrochloric acid.

$$CaO + 2HCl = CaCl_2 + H_2O$$
$$CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2$$

Calcium chloride will form crystals containing water, for example, $CaCl_2 \cdot 6H_2O$, and when the water is removed by strong heat, the anhydrous salt will readily absorb water again. On account of being thus hygroscopic, calcium chloride is frequently used for drying gases or liquids.

Chloride of Lime.—This is the name often given to a substance formed by saturating slaked lime with chlorine. Its composition is probably represented by the formula $CaOCl_2$. It is a white powder which readily sets free chlorine, when treated with an acid.

$$CaOCl_2 + 2HCl = CaCl_2 + H_2O + Cl_2$$
$$CaOCl_2 + H_2SO_4 = CaSO_4 + H_2O + Cl_2$$

The chlorine thus obtained is largely used for bleaching cotton and linen, and the chloride of lime is therefore called *Bleaching Powder.*

Calcium Sulphate occurs in nature as gypsum ($CaSO_4 \cdot 2\,H_2O$). It is slightly soluble in water, but enough of it is found in many waters used for steam making to form an extremely hard scale in the boilers. Its complete removal before the water enters the boiler, is an important and unsettled problem, but th addition of a proper amount of sodium carbonate is of considerable help.

When carefully heated to 230° F., gypsum loses about three-fourths of its water of crystallization. The resulting powder, when stirred with water into a paste, *sets* firmly, or becomes a hard mass, and under the name of *Plaster of Paris* is largely used for making casts.

Calcium Phosphate ($Ca_3(PO_4)_2$) occurs in nature as the mineral phosphorite, and also in the bones of vertebrate animals. When treated with sulphuric acid in proper proportions, this insoluble normal phosphate is changed to the soluble *primary* phosphate, which is then used as an artificial fertilizer, under the name of *superphosphate of lime.*

$$Ca_3\,(PO_4)_2 + 2H_2SO_4 = 2CaSO_4 + CaH_4\,(PO_4)_2$$

Calcium Silicate ($CaSiO_3$) is important because it is a constituent of almost all sorts of glass. Alone, it is very hard to fuse, and tends to become crystalline, but when mixed with potassium silicate, K_2SiO_3, or sodium silicate, Na_2SiO_3, the mass becomes fusible at moderate temperature, transparent, amorphous. and practically insoluble in all ordinary liquids. This is the common window glass and bottle glass of commerce. It is made by fusing together clean sand, lime, and soda.. By using lead oxide instead of lime, we obtain a glass that is softer and more fusible, but is highly refractive, and takes a beautiful lustre when polished. It is used for *cut glass* ware.

ACIDS.

The three acids most common and important commercially are sulphuric acid; H_2SO_4; hydrochloric acid, HCl; and nitric acid, HNO_3.

Sulphuric Acid is the most important chemical in the arts because it is the basis of many chemical industries, and its low cost gives it preference over other acids. It is made from sulphur or the sulphur in iron pyrites, FeS_2. The sulphur is burned to sulphur dioxide, SO_2; oxygen in the presence of water is added producing sulphuric acid. The reactions are:

$$(1)\quad S + O_2 = SO_2$$

$$(2)\quad SO_2 + O + H_2O = H_2SO_4$$

The action of the oxygen of the air on SO_2 is very slow and the aid of the oxides of nitrogen is necessary to make the process a success.

Nitrogen peroxide NO_2 parts with one atom of oxygen easily in the presence of SO_2 and moisture, forming sulphuric acid and NO gas.

$$SO_2 + NO_2 + H_2O = H_2SO_4 + NO$$

When the NO gas thus formed comes in contact with atmospheric oxygen the NO readily takes on an atom of oxygen and is restored to NO_2. Thus the NO_2 acts as a "carrier of oxygen." By a suitable arrangement of absorbing towers these oxides of nitrogen are used over and over again.

The manufacture of sulphuric acid takes place in a series of immense sheet-lead chambers, which may be over one hundred feet long. The FeS_2 or sulphur is burned in kilns, and the SO_2 gas passes through a tower where it takes up NO gas and moisture. It then passes into the first chamber where more water is introduced in the form of steam. The sulphuric acid forms at once as a white mist which gradually settles to the bottom of the chamber. The process continues in the following chambers and the NO_2 gas is absorbed in a tower at the end of the series to be used over again. The process is continuous. The weak "chamber acid" formed is evaporated in lead pans and finally in platinum to form the thick, heavy, oily liquid commonly called "oil of vitriol." This contains about 95 per cent of real sulphuric acid, H_2SO_4.

Sulphuric acid of high strength is now being made by the contact or "calalitic" process. In this process a mixture of sulphur dioxide, SO_2 and air is passed through a heated tube containing spongy platinum. In some unknown way, the heated platinum brings the SO_2 and the oxygen of the air together forming SO_3 which combines with water making H_2SO_4. This new process bids fair to replace the "lead chamber" process.

The sulphates of lead, barium and strontium are insoluble, and that of calcium only slightly so; other sulphates are soluble.

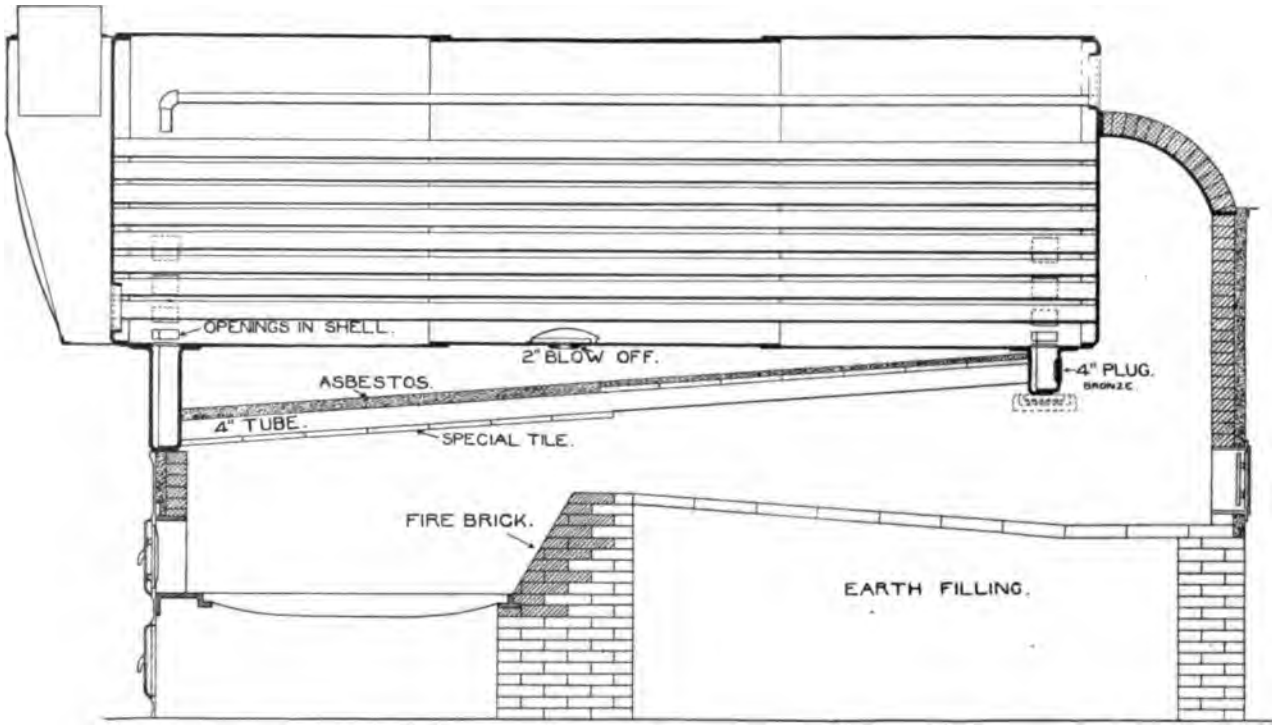
Hydrochloric acid is made, as is described in the manufacture of soda ash by the LeBlanc process, by heating common salt with sulphuric acid. In this country where the LeBlanc process is not used, the hydrochloric acid is the principal product and the sulphate of soda also obtained is the bi-product. The hydrochloric acid gas, HCl, given off is absorbed by water in earthenware receivers and towers until the solution is of a certain strength, when it is drawn off into glass carboys for sale, making the "muriatic acid" of commerce. It varies in strength from 36 per cent to 29 per cent real HCl gas. When chemically pure it is colorless, but the usual commercial acid is colored yellow from a small amount of iron. All the salts of this acid are very soluble with the exception of the chloride of silver, one of the chlorides of mercury and the chloride of lead; this last is soluble in hot water. Hydrochloric acid is a better solvent than sulphuric acid for some substances.

Nitric acid is produced by heating nitrate of soda with sulphuric acid and condensing the nitric acid driven off in glass or earthen receivers. The pure acid is colorless, but the commercial acid is frequently colored yellow or red by the oxides of nitrogen. It is sold in glass bottles or carboys in strength from 67 per cent to 53 per cent real HNO_3. This acid is the best solvent for most metals because it combines an oxidizing action with its dissolving properties. It is frequently used in connection with the other acids for this reason. A mixture of three parts hydrochloric acid and one part nitric acid forms *aqua regia*, which will dissolve the noble metals, gold and platinum.

COMMON CHEMICALS.

Trade Name.	Chemical Name.	Chemical Formula.	Physical Condition.	* Price.	Use and Remarks.
		ALKALINE SUBSTANCES.			
Soda Ash Alkali	Sodium Carbonate (anhydrous)	Na_2CO_3	White Powder	1¼	Making caustic soda, sodium salts, etc.
Washing Soda Sal Soda Soda	Sodium Carbonate (crystalline).	$Na_2CO_3 . 10H_2O$	Transparent Crystals	$\frac{3}{5}$	Washing, Deliquesces to white powder.
Baking Soda	Sodium Bicarbonate	$NaHCO_3$	White Powder	1½	Cooking, baking powder.
Caustic Soda Caustic Alkali	Sodium Hydrate	$NaOH$	Waxy Solid or Powder	3	Makes hard soaps.
Lye Caustic Potash	Potassium Hydrate	KOH	Waxy Solid or Powder	6	Makes soft soaps; most "lye" sold is caustic soda.
Potash	Potassium Carbonate	K_2CO_3	White Powder	5½	Made from wood ashes
Pearl Ash	Potassium Carbonate	$K_2CO_3 . 2H_2O$	White Crystals	7	Used for wool scouring.
Salaratus	Potassium Bicarbonate	$KHCO_3$	White Powder	14	Sodium bicarbonate is called Salaratus.
Aqua Ammonia	Ammonium Hydrate	NH_4OH	Colorless Liquid	6	26° ammonia is 33% NH_3 gas. "Household" ammonia is 10% NH_3 or less.
Borax	Sodium Borate	$Na_2B_4O_7 . 10H_2O$	White Powder	7½	Mildly alkaline, a preservative.
		ACIDS.			
Oil of Vitriol	Sulphuric Acid	H_2SO_4	Oil-like Liquid	1½	Sold 66° Baume'.
Muriatic Acid	Hydrochloric Acid	HCl	White or Yellow Liquid	2¼	Sold 18°, 20°, 22° Baume .
Nitric Acid Aqua Fortis	Nitric Acid	HNO_3	White or Yellow Liquid	6	Sold 36° to 42° Baume'.
Acetic Acid	Acetic Acid	CH_3COOH	White Liquid	10	Sold 100% to 28%. The acid in vinegar.
		SALTS.			
Alum	Potassium Aluminum Sulphate	$KAl(SO_4)_2 . 12H_2O$	Translucent Crystals	2	Sizing paper, clarifying water, dyeing; is being replaced by aluminum sulphate $Al_2(SO_4)_3 . 18H_2O$
Blue Vitriol	Cupric Sulphate	$CuSO_4 . 5H_2O$	Blue Crystals	6	Copper plating, dyeing, fungicides.
White Vitriol	Zinc Sulphate	$ZnSO_4 . 7H_2O$	White Crystals	3	Dyeing, glue making, disinfectant.
Green Vitriol Copperas	Ferrous Sulphate	$FeSO_4 . 7H_2O$	Green Crystals	⅝	Dyeing, deoderizer, ink making.
Epsom Salts	Magnesium Sulphate	$MgSO_4 . 7H_2O$	Transparent Crystals	1½	Loading cotton fabrics.
Sal-Ammoniac	Ammonium Chloride	NH_4Cl	Waxy, Solid or Crystals	7	Batteries, flux in galvanizing iron.
Sugar of Lead	Lead Acetate	$Pb(C_2H_3O_2)_2 . 3H_2O$	Lumps or Fine Crystals	6	Dyeing, colors.

*Prices given are in cents per pound and are approximate for goods in original packages.



BONSON FURNACE AND HORIZONTAL RETURN TUBULAR BOILER.

Bonson Furnace & Boiler Co.

CONSTRUCTION OF BOILERS.

A steam boiler, or steam generator, consists of a vessel to contain the water and the steam after it is formed; a fire-box to contain the fire; tubes, flues and uptake to transmit heat and conduct the hot gases from the fire to the chimney, and various fittings to facilitate the safe and economical operation. Boilers are often classified according to their uses and conditions; thus we have stationary, marine and locomotive boilers. Boilers having a shell partially filled with tubes, through which the hot gases pass, are called tubular, fire-tube or shell boilers; and those having a large flue in which is placed the fire, are called flue boilers. If the tubes are filled with water and the hot gases are outside, the boiler is called a water-tube boiler.

Steam boilers are made in a variety of shapes, according to the type, uses and conditions. Let us first consider boiler construction in general, leaving out the peculiarities of marine, locomotive and water-tube boilers.

MATERIALS.

The materials of which boilers are constructed are exposed to conditions which weaken them and shorten the life of the boiler. Among these conditions are corrosion, both external and internal, high pressure, and expansion and contraction, due to varying temperature and pressure.

Cast iron was the material of which the earliest forms of boilers were made, but on account of its low tensile strength and its unreliable nature, it is now but little used, except for parts of water-tube boilers, and sometimes for the ends of low-pressure cylindrical boilers and for fittings. It is cheap and resists corrosion but on account of its unreliability and brittleness, the parts must be made thick and therefore heavy.

Wrought iron, up to about 1870, was the principal material used for boiler plates. It is a pure iron prepared from pig iron by a process called puddling, described in "Metallurgy." Wrought iron is well adapted for use in boiler construction, as it is strong, tough and fibrous, and combines high tensile strength with ductility and freedom from brittleness. When the properties mentioned are well combined, wrought iron will resist strains due to unequal expansion. Boiler fastenings, stays and other parts made by welding are sometimes made of wrought iron. It is customary to consider that a bar loses about one-quarter of its strength by welding, although it is often stronger in the weld, owing to the working of the metal during the welding process.

Steel has entirely displaced iron for boiler-shell work. Boiler steel is made by the open-hearth process, and contains for ordinary thickness of 1 or 1¼ inches 0.25 per cent carbon, while thinner plates of ¼ inch should not contain over 0.15 per cent carbon. Larger percentages of carbon, while accompanied by an increase in tensile strength, lessen the ductility. The following properties show steel to be the best boiler material at present: great tensile strength, ductility, homogeneity, toughness, freedom from blisters and internal unsoundness. Blisters and unsoundness are faults sometimes met with in wrought-iron plates.

Copper in many respects is superior to wrought iron for boiler construction. It is homogeneous, resists oxidation (the corrosive action of most feed waters) and incrustation. It is more ductile and malleable and a better conductor of heat, which not only gives it a higher evaporative power, but also enables it to last longer under the intense heat of the furnace. Its disadvantages are its low tensile strength, about 30,000 pounds per square inch, and its decrease of strength with an increase of temperature. In heating from the freezing point to the boiling point it loses 5 per cent of its strength, and at 550° F. it loses about one-quarter of its strength. For these reasons and on account of its high price, it is now seldom used in boiler work.

Brass is an alloy of copper and zinc in which the proportions of each vary considerably. The red color comes from a larger per cent of copper. Red brass is better and more expensive than yellow brass. Brass is used for valves, gauges and other fittings.

Bronze is an alloy of copper and tin, and is advantageously used for valves and seats of safety valves where the wear is great.

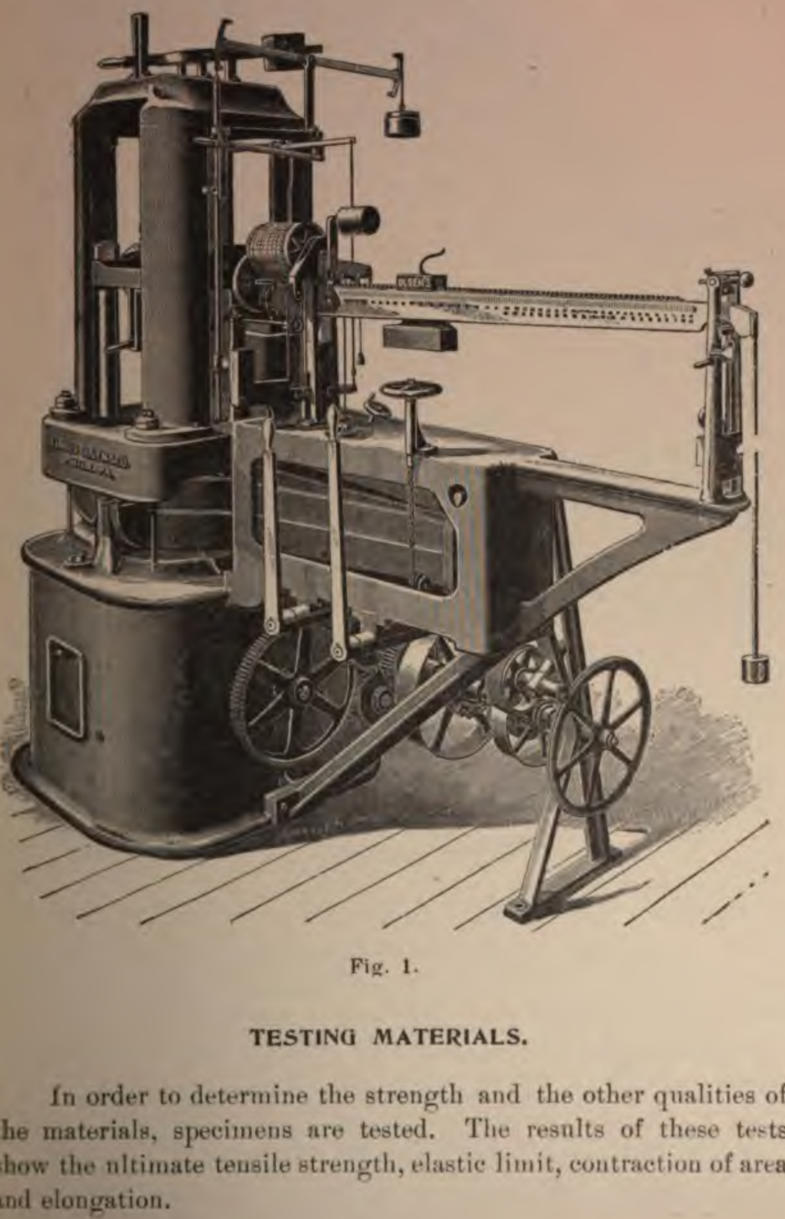


Fig. 1.

TESTING MATERIALS.

In order to determine the strength and the other qualities of the materials, specimens are tested. The results of these tests show the ultimate tensile strength, elastic limit, contraction of area and elongation.

The simplest way to test a piece of iron bar or plate would be to fix it firmly at the upper end and hang weights on the other end, adding other weights until the bar is broken. This is but a crude method, and in order that the elastic limit and elongation may be determined at the same time, testing machines are used. There is a large variety of testing machines, adapted for various materials, but the general principles are the same.

Testing Machines. The testing machine consists of a frame and two heads, to which the ends of the test piece are fastened by wedges or other devices. By means of steam or hydraulic power one head is drawn away from the other for tensile tests. The pull is transmitted to some weighing device, usually levers and knife edges like the beam of ordinary platform scales. In small machines the pull may be applied by a lever.

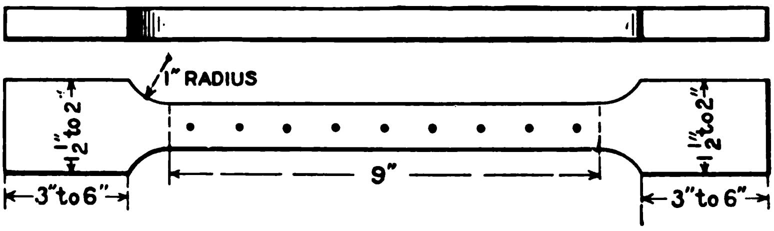


Fig. 2.

Testing machines are made for all varieties of testing: tensile, compressive and shearing stresses. Also for deflection of beams and for strength of wood, cement, brick and stone. Fig. 1 shows an Olsen testing machine designed for tensile and compressive tests of iron and steel.

In order to test materials, test pieces or specimens are prepared. For testing iron plate the test piece should be at least 1 inch wide, about 2 feet long and planed on both edges. Many engineers recommend these dimensions. According to the Board of Supervising Inspectors of Steam Vessels, the test piece should be 10 inches long, 2 inches wide and cut out at the center.

To ascertain the tensile strength and other qualities of steel, a test piece should be taken from each plate. These test pieces are made in the form as shown in Fig. 2. The straight part in the center is 9 inches long and 1 inch wide; and to determine elongation it is marked with light prickpunch marks at distances 1 inch apart, the marked space being 8 inches in length. The ends are $1\frac{1}{8}$ inches to 2 inches broad and 3 inches to 6 inches long.

As has been explained in "Mechanics," the force necessary to break the piece is the proportionate part of the tensile strength per square inch. Thus if the test piece having a reduced section of .4 square inch is broken at 19,200 pounds, the tensile strength of the plate is $\frac{19,200}{.4} = 48,000$ pounds per square inch.

EXAMPLES FOR PRACTICE.

1. If a piece of boiler plate breaks at 33,500 pounds and the reduced section is $1\frac{1}{8}$ inches by $\frac{1}{2}$ inch, what is the ultimate tensile strength?

Ans. 59,555 pounds.

2. A boiler plate is claimed to be of 64,000 pounds tensile strength. If the section is 1 inch wide and .63 inch thick, what should be the reading of the testing machine when the specimen breaks?

Ans. 40,320 pounds.

3. A test piece of the form shown in Fig. 2 measured 8 inches between the prickpunch marks before testing and 9.56 inches after testing. What was the per cent of elongation?

Ans. $19\frac{1}{2}$ per cent.

4. If the area of section before breaking is .4825 square inch and after breaking is .236 square inch, what is the per cent of reduced area?

Ans. 51 per cent.

STRENGTH OF BOILER MATERIALS.

The crushing strength of cast iron is high, varying from 50,000 to 75,000 pounds per square inch; its tensile strength is low, varying with the chemical and physical properties of the iron from about 15,000 to 22,000 pounds per square inch.

Wrought-iron plates having a tensile strength of from 50,000 to 60,000 pounds, with an elongation or ductility of from 20 per cent to 30 per cent, are suitable for boiler work. Boiler iron may be tested in the following ways if testing machines are not available: Cut from the plate a strip about 2 inches wide and bend it cold, down upon itself; if it shows no fracture on the outside curve, it is satisfactory. This is, however, a severe test, and only the best flange iron will stand it; on the other hand, any iron which, when heated to a cherry red and bent, shows cracks or fracture on the outer curve, is unfit for use in boiler construction. When wrought iron was used for boiler plates it was customary to give the plate what is called the hammer test. The plate was suspended clear of the ground and struck with a hammer at intervals of three or four inches over its surface; a clear, ringing tone indicating a sound plate, while a dull sound indicated with fair certainty a defect such as internal unsoundness.

Mild steel has a tensile strength of from 55,000 to 65,000 pounds per square inch, with an elongation of 25 per cent. A test piece cut from a plate $\frac{3}{4}$ inch thick or less should stand bending double, when hot or cold, and not show any cracks; thicker plates should be capable of being bent at a small radius to a large angle without showing any cracks. Steel should never be worked at a blue heat, as in this state it is very brittle. It is also mechanically tested by being heated to a cherry red, quenched in water at 82° F. then bent in a curve of small radius; if it cracks, it has become tempered, and it is therefore unsuitable for this work. If the tensile strength of the steel is under 70,000 pounds per square inch, it is sufficiently tough and ductile and can be easily worked.

In general, boiler materials are carefully tested for the following qualities:

Tensile strength, to resist rupturing strains. Also in order that the plates may be thin.

Toughness and elasticity, to resist corrosion and the wear and tear of manufacture.

Ductility, so that the boiler may change its shape slightly without rupture. This is a more important quality.

BOILER CONSTRUCTION IN DETAIL.

The drawing or design of the boiler is worked out in the draughting room, as explained later under the head of Boiler Design.

The draught shows the general arrangement of the boiler, together with complete detail drawings, from which the materials are ordered. These materials are plates, rods for stays, rivets, stay bolts, tubes, steel bars, angles and channel bars for stiffening, etc.

In some boiler shops it is customary to lay the boiler out on a large blackboard full size, thereby checking the drawing. In ordering plates the blank forms are filled out in the following manner:

Messrs. John Blank & Co:

Please furnish us with the following Steel Plates, Ultimate Tensile Strength, *60,000;* Elongation, *25 per cent:*

Number wanted.	Thickness	Dimensions.	Marks.	Remarks.
6	1″	90″×70″	S 14	Shell

The dimension which runs in the direction the plate is to be bent is given first. The plates are marked as per order blank, and this serves to identify the plate when the occasion arises. When ordering any odd shape, a sketch with dimensions must be placed in the column headed "Remarks."

In ordering plates, allow for trimming, particularly in the case of irregular shapes. Rivets are sold by the pound, regardless of their shape or size. Round and flat iron may be ordered by the running foot. Manufacturers publish tables showing weight of rivets, round iron, etc., with which they furnish boiler makers.

Boiler shops are equipped with the following tools: plate rolls, plate planers, shears, drill presses, punches, countersinking machines, flanging machines, hydraulic and steam riveters, and a compressed-air system for operating pneumatic machines, such as calkers and chippers. They also have machine shops for doing such machine work as is required for fittings, furnace fronts, etc., and a system of cranes for handling and transporting material. In connection with the above is a storeroom of sufficient size, a forge shop, and an engine and boiler for supplying the shop with the power necessary to operate it.

In boiler-shell work drilling has entirely displaced punching, and to-day all holes are drilled. Punching is cheaper than drilling, but it is more injurious to the plates and not as accurate. It is easy to see that drilling rivet holes, even if twenty are being drilled at once, is done with less strain on the plates than when done by a multiple punch forcing several holes at once. The force required to punch a plate gives the best idea of the harm done to the plate. Experiment shows that the resistance of a plate to punching is about the same as its resistance to tensile tearing. Suppose this to be 50,000 pounds per square inch; then the force required to punch the plate is the area cut out times the shearing strength, or $d \times \pi \times t \times 50,000$.

In which formula

d = diameter in inches and

t = thickness in inches.

For a hole $\frac{3}{4}$ inch in diameter in a $\frac{1}{2}$-inch plate, the force will be

$$\tfrac{3}{4} \times 3.1416 \times \tfrac{1}{2} \times 50,000 = 58,900 \text{ pounds.}$$

If the force required to punch one hole is 58,900 pounds, the force required in punching several holes by means of a multiple punch is enormous.

A good, ductile plate is but little injured by punching; but if of a hard, steely nature, it is likely to be seriously injured. For this reason wrought-iron plates are usually punched and steel plates are drilled. On the whole, a drilled plate is somewhat stronger than a punched plate for any kind of joint.

Some boiler makers punch the rivet holes slightly smaller than the desired size and then ream them out. By this process the injured metal around the holes is cut away. Another method to overcome the injurious effects is to anneal the plate after punching.

The ordinary process of annealing consists of heating the plate to red heat, and then allowing it to cool slowly. By this

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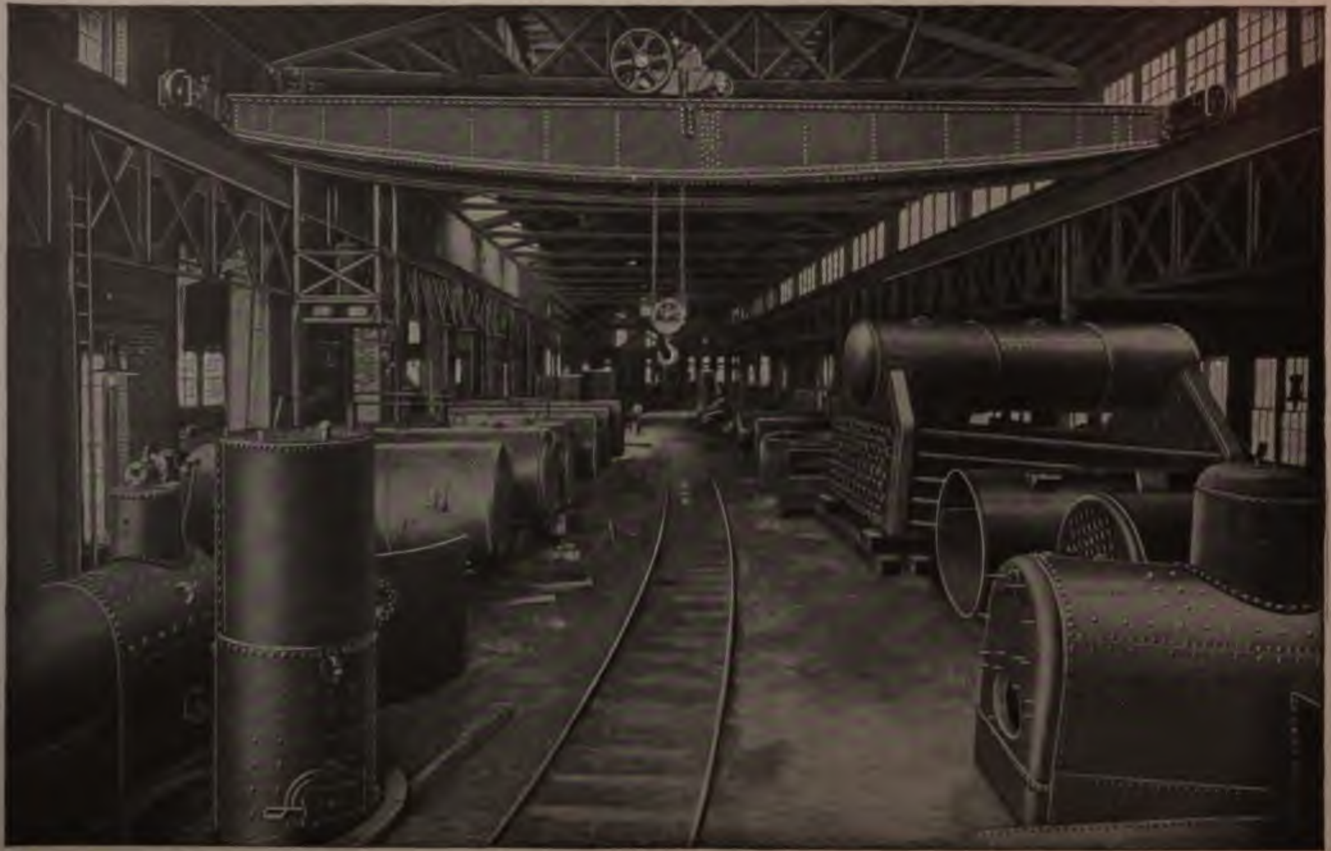


ERECTING SHOP.

means, hard and brittle iron or steel is made soft and tough. While the metal is hot, the surface becomes oxidized. For most purposes this scale of oxide in not harmful, but in some cases it must be removed. As this is expensive, a process of annealing in illuminating gas has been devised. The action of the gas is to reduce the oxide without altering the properties of the piece. The results obtained from annealing depend upon the kind of iron or steel, the temperature to which it is raised, and the rate of cooling. It is a great advantage to all steel of over 64,000 pounds per square inch in tensile strength, but softer steels are little better for the process.

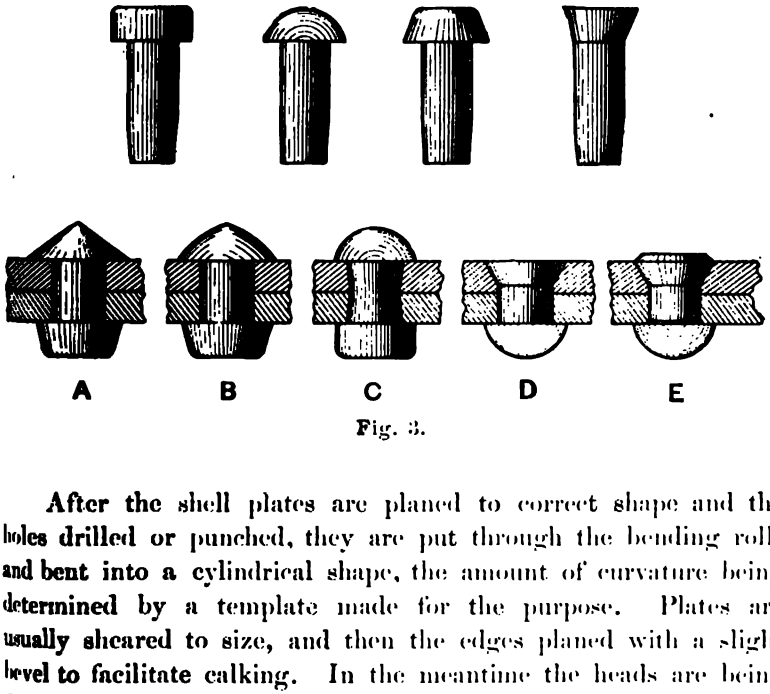


Fig. 3.

After the shell plates are planed to correct shape and the holes drilled or punched, they are put through the bending rolls and bent into a cylindrical shape, the amount of curvature being determined by a template made for the purpose. Plates are usually sheared to size, and then the edges planed with a slight bevel to facilitate calking. In the meantime the heads are being flanged by a hydraulic flanging machine; when the flange is completed, the head is put on the platen of a boring mill and turned so as to exactly fit into the shell. In some shops it is customary to punch or drill only a few holes in the shell and flange of the head, these holes serving to take bolts for holding the parts together. The back head plate is bolted into the rear course of plating, and the parts thus assembled are hoisted up to drill if the plates, etc., have not been previously drilled or punched, otherwise to the hydraulic riveter.

RIVETS AND RIVETING.

Rivets are formed by forging, from round iron bar or mild steel, with a cup or pan shaped head. The cylindrical part, called the shank, is a little smaller than the hole and has a slight taper. Fig. 3 shows common forms of rivets. As rivets are not as reliable in tension as in shear, they are used mainly at right angles to the straining force. If the stress is parallel to the axis, bolts are used, since they are strong in tension. The shearing strength of steel rivets is about 45,000 pounds per square inch, and of iron rivets about 40,000 pounds per square inch. Steel rivets are often used with steel plates, but many boiler makers prefer to use iron rivets in all cases.

Three types of rivets in use are shown in Fig. 4, the following table giving the dimensions:

Diameter of Rivet.	Cone Head. A			Countersunk. B		Button Head. C	
D	E	F	G	E	G	E	G
$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{19}{32}$	$\frac{9}{16}$	$1\frac{1}{16}$	$\frac{9}{32}$	$1\frac{1}{16}$	$\frac{7}{16}$
$\frac{11}{16}$	$1\frac{1}{8}$	$\frac{21}{32}$	$\frac{39}{64}$	$1\frac{3}{16}$	$\frac{5}{16}$	$1\frac{1}{8}$	$\frac{1}{2}$
$\frac{3}{4}$	$1\frac{1}{4}$	$\frac{23}{32}$	$\frac{21}{32}$	$1\frac{1}{4}$	$\frac{3}{8}$	$1\frac{1}{4}$	$\frac{9}{16}$
$\frac{7}{8}$	$1\frac{7}{16}$	$\frac{13}{16}$	$\frac{3}{4}$	$1\frac{3}{8}$	$\frac{7}{16}$	$1\frac{7}{16}$	$\frac{3}{4}$
1	$1\frac{5}{8}$	$\frac{15}{16}$	$\frac{27}{32}$	$1\frac{5}{8}$	$\frac{1}{2}$	$1\frac{5}{8}$	$\frac{3}{4}$

Formerly all joints of boilers were riveted by hand, but now all riveting is done by machines, except those joints to which a machine cannot be applied. If done by hand, the red-hot rivet is inserted in the hole, and the second head formed by two riveters working with hammers. This head is either made conical by the hammers alone or finished with a cup-shaped die called a "snap." This latter is the more usual method. The disadvantages of hand riveting are slowness and a tendency to form a shoulder before the rivet fills the hole.

Machine riveting is preferable, as the work is done better, faster and more accurately; the pressure coming gradually on the entire rivet, compresses it completely into the hole before the head is formed. Before riveting, care should be taken that the plates are close together, so that a shoulder will not be formed between the plates and prevent a good joint. Rivets should always be put in while red hot, for in this condition they are more easily worked, and when they cool they contract, nipping the plates together in a tight joint.

Hydraulic riveting is more gradual and is generally preferred to steam riveting. The pressure from the steam riveter often comes as a sudden blow and does not allow time for the rivet to completely fill the hole.

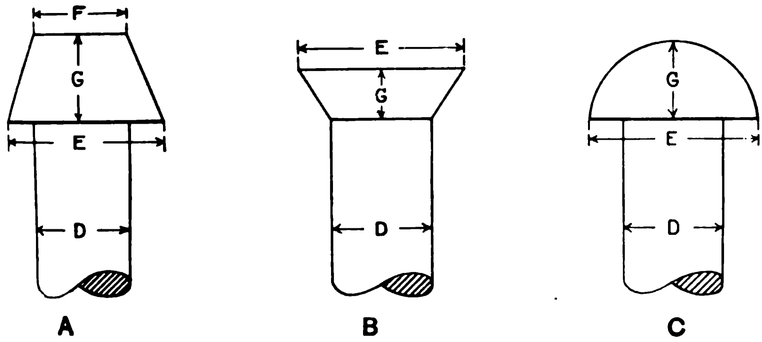


Fig. 4.

It is sometimes desirable to rivet with a countersunk head; that is, the rivet does not project above the plate. The countersunk head is formed by hammering down the end of the rivet into the countersink in the plate. This form is shown at D, Fig. 3. This joint is often used in shipbuilding and in boiler making when it is necessary to attach mountings. It should always be avoided, if possible, on account of its weakness, and especially when the straining force acts in the direction of the length of the rivet, as the head has a very insecure hold and is likely to be pulled through the hole.

Rivets may be tested in a boiler shop as follows: the rivet to be bent cold in the form of a hook around another rivet of the same diameter, and show no flaws or cracks; to be bent hot down upon itself and show no cracks, head to be flattened while hot until its diameter is 2½ times the diameter of the shank, and show no flaws.

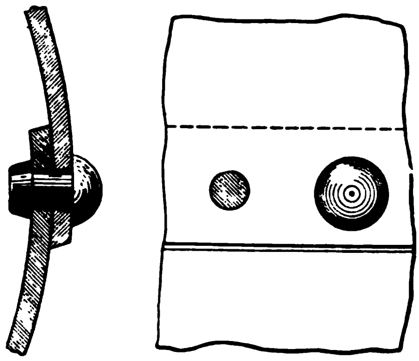


Fig. 5.

The uniform heating of steel rivets is of more importance than in the case of iron rivets, where it is sufficient to heat the points only. Steel rivets also should not be heated to a white heat, as iron rivets are, but to a bright cherry red, for if heated beyond this point they will burn. The fire in which steel rivets are heated should be kept thick, and the draught moderate. This should also be observed in heating steel plates for flanging.

There are various forms and strengths of riveted joints. It is obvious that in punching or drilling, a plate is weakened to the extent of the sectional area cut out, and that if the holes are punched, the metal between the holes is weakened. In treating the strength of a joint it is customary to speak of it as a percentage of the strength of an unpunched plate.

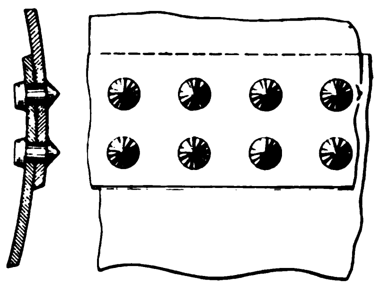


Fig. 6.

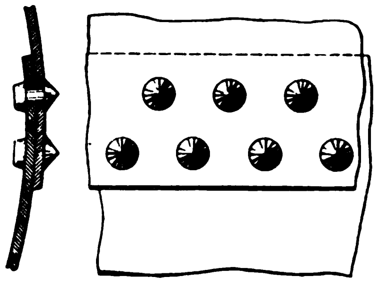


Fig. 7.

If one plate overlaps another and is riveted to it by a single row of rivets, as shown in Fig. 5, it is called a single-riveted lap joint. This joint has about 56 per cent of the strength of a solid plate. If another row of rivets is added, it is called a double-riveted lap joint; Fig. 6 shows the double-riveted lap joint chain riveted, and Fig. 7 the double-riveted lap joint zigzag riveted.

Double riveting is done in two ways: zigzag, or staggered, and chain. When rivets are put in so that the rivets of one row are opposite the spaces of another row, it is called zigzag riveting or staggered riveting. If the rivets are placed immediately opposite each other, it is called chain riveting.

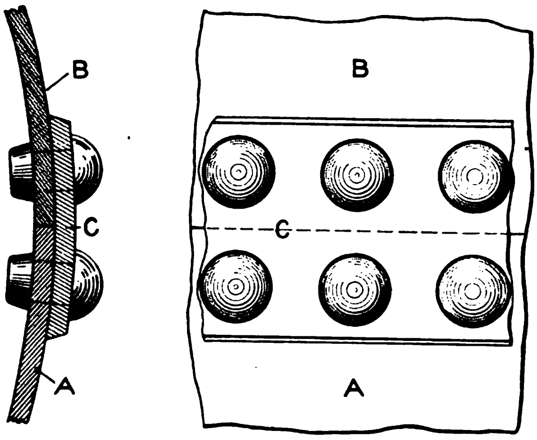


Fig. 8.

If the two plates are kept in the same plane and a cover or butt strap riveted on, it is called butt riveting (Fig. 8, in which A and B are the boiler plates, and C is the butt strap). If an inside butt strap is added, it is called a double butt joint (Fig. 9). Fig. 10 shows a treble-riveted butt joint. A single butt joint is about equal in strength to a lap joint having but one row of rivets, but a double butt joint is considerably stronger.

In this latter form of joint the rivets have double shearing surfaces, since they tend to shear off in two planes. This either makes a stronger joint or allows the use of smaller rivets. In the single butt joint the butt strap is usually about $1\frac{1}{8}$ the thickness of the plate, and if the inside butt strap is added, each butt strap is made about $\frac{5}{8}$ the plate thickness. Butt joints are now bein used in the best class of boilers, and are used almost entirely fo plates less than $\frac{1}{2}$ inch in thickness.

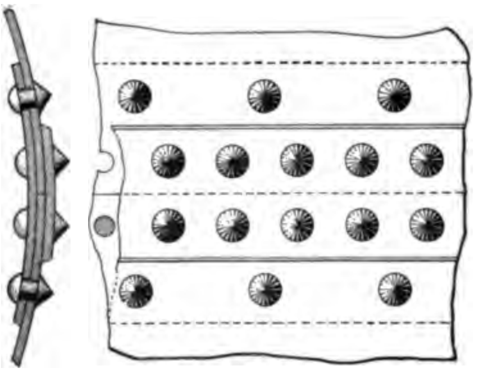


Fig. 9.

Lap joints are use for circumferentia seams, and the stronge joint, the butt, for long tudinal joints. For hig pressures in marin boilers, triple rivetin is frequently used.

If a cover plate i riveted on the outsid of a lap joint, it is calle combined lap and bu joint. In this cas there are three rows of rivets, the middle row having twice a many rivets as the outer rows. Fig. 11 shows the combine joint.

The distance between the centers of rivets is called th "pitch." The mathematical calculation of pitch and the distanc between the rivets and the edge of the plate will be taken u later.

The following table gives an idea of the relative strengt of riveted joints:

Kind of Joint.	Riveting.	Percentage of Strength.	
		Punch.	Drilled.
Lap	Single Double	55 69	62 75
Single Butt	Single Double	55 69	62 75
Double Butt	Single Double	57 72	67 79

FLANGING IRON AND STEEL PLATES

Iron plates are more severely tested by flanging than by any other work done upon them. This is due to their fibrous nature, and great care is necessary to prevent breaking in the bend, if the corner is sharp.

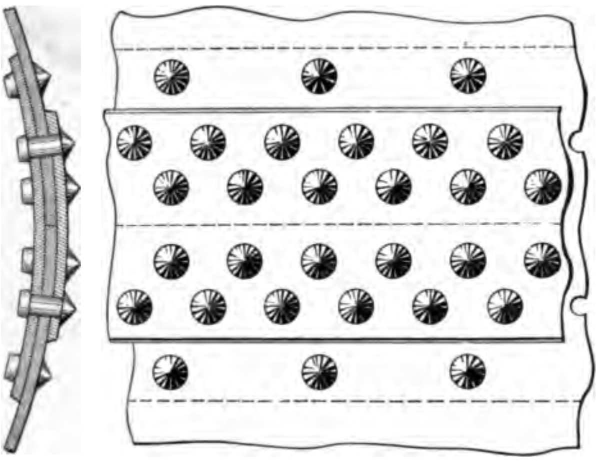


Fig. 10.

As has been stated, steel requires uniform heating and moderate curves. Flanging is almost entirely done to-day by machines. After flanging, the steel should be annealed by heating the whole plate uniformly to a dull red heat, and allowing it to cool slowly.

WELDED JOINTS.

Welded joints for boiler shells are desirable. By their use deposits which accumulate on and around rivet heads and joints, corrosion caused by leakage, and loose rivets, are done away with, and calking also. Moreover, a perfectly welded joint is stronger than the best riveted joint, and approximates nearly to the original strength of the plate. Welded steam drums are used now quite extensively for water-tube boilers of the marine type.

The soundness of such a joint is a matter of uncertainty, and depends upon the skill and care of the workmen. It is impossible, from external appearances, to judge the soundness of a welded joint. The principal use of welded joints is for furnace tubes and steam domes, but they have not been used much for boiler shells. The lack of tests on welded joints and the small amount of information on the subject, render the results of experiments of little value. The weld is best made when the edges of the plates are upset, at red heat, to nearly double the plate thickness, and beveled to an angle of about 45 degrees. The edges are then heated together, and the weld made by hammering down the joint to the original thickness of th' plate.

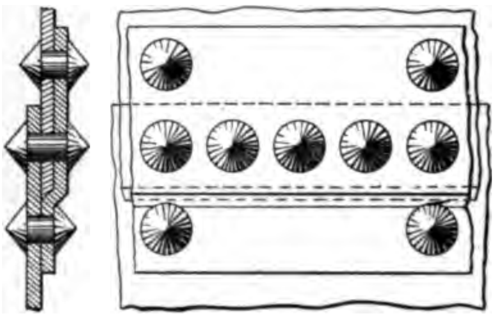


Fig. 11.

ARRANGEMENTS OF PLATES AND JOINTS.

When we take up the design of boilers we shall see that a boiler tends to rupture longitudinally. The reason for this is that the resistance of a thin cylinder to circumferential rupture is double the resistance to longitudinal. Since this is the case, lap joints are used for transverse seams, and a stronger form (the double butt joint) is used for the longitudinal.

At the junction of three or more plates, where the circumferential and longitudinal joints meet, ordinary riveted joints would be too thick. To overcome this difficulty, two or more plates are forged thin at the joint, as shown in Fig. 12.

Whenever longitudinal and girth seams meet, the plates should be arranged to "break joints"; that is, one longitudinal seam should not be a continuation of another. The proper arrangement is shown in Fig. 13.

In both vertical and horizontal boilers the inside lap is made to face downward, so that it will not form a ledge for the collection of sediment

The belts of plates that make up the length are sometimes arranged conically, with the outside lap facing backward. When the boiler is slightly inclined toward the front end, this conical arrangement facilitates draining and cleaning, as the dirt is removed at the front end. This is a great advantage to internally fired boilers, as they are difficult to clean.

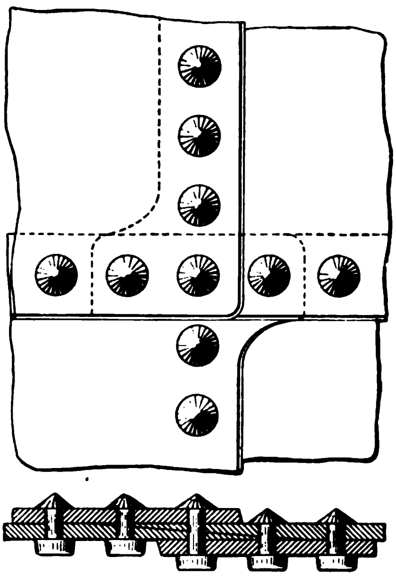


Fig. 12.

In long vertical boilers the ring seams are arranged with the inside lap facing downward, so as not to have a ledge for sediment. Sometimes the belts of locomotive boilers are arranged telescopically, with the largest diameter at the fire-box end. Of late years the best makers use larger plates than formerly. This is advantageous, especially in externally fired multitubular boilers, as the single seam is placed above the water-level, and therefore is away from the fire.

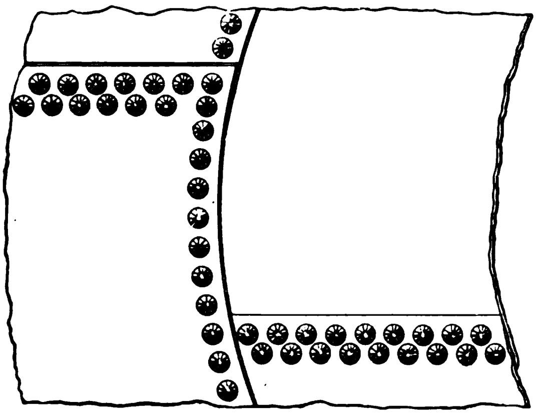


Fig. 13.

The portion of a boiler between the shell and the furnace is called the water leg. Figs. 14 to 20 inclusive illustrate the method of construction of the water leg and the joints around the furnace door. Figs. 14 and 15 show two methods of constructing the water leg. In Fig. 14 the exterior plate and the furnace plate are riveted to the ring D by means of long rivets. This ring is usually made of wrought iron, but in many cheap boilers it is of cast iron. In Fig. 15 the two plates are riveted to the flanged ring D. This construction is better than the solid cast-iron ring, on account of flexibility, but the junction of the plates D and C

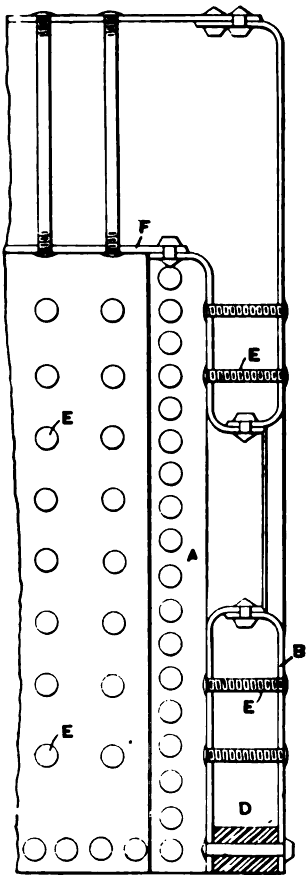


Fig. 14.

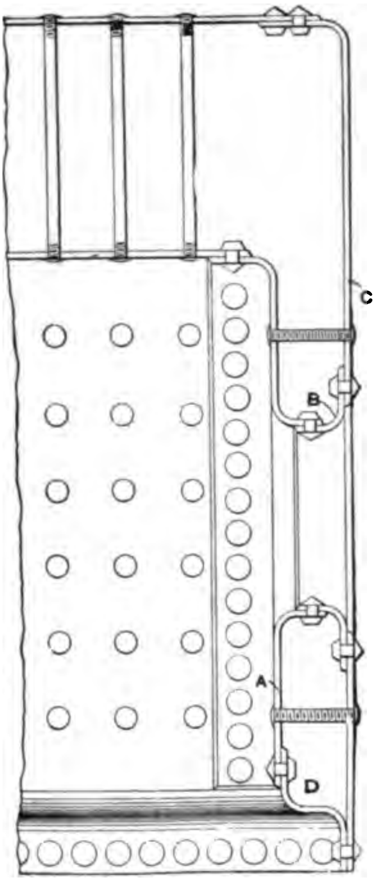


Fig. 15.

forms a corner in which sediment is deposited. In Fig. 17 the plate B is flanged and riveted to C. This arrangement requires less riveting than the one shown in Fig. 15. Figs. 14, 15 and 17 also show three forms of construction of the joints around the furnace door. In Fig. 14 both the exterior plate and the furnace sheet are flanged and riveted together. This is shown in an enlarged view in Fig. 18. The construction shown in Figs. 15 and 19 is not as good as that in Fig. 14, because of the extra riveting; also, it has two corners, B and C, for the deposit of sediment. Fig. 17 shows a somewhat different form of furnace construction,

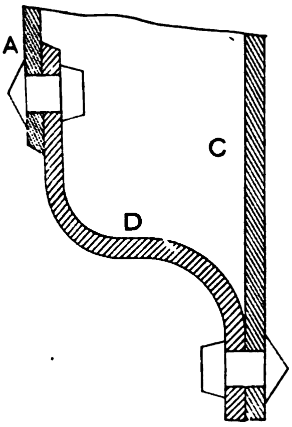


Fig. 16.

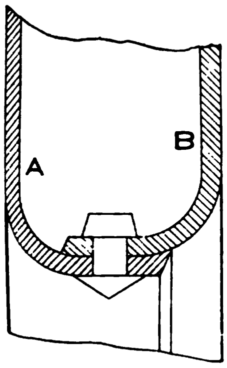


Fig. 18.

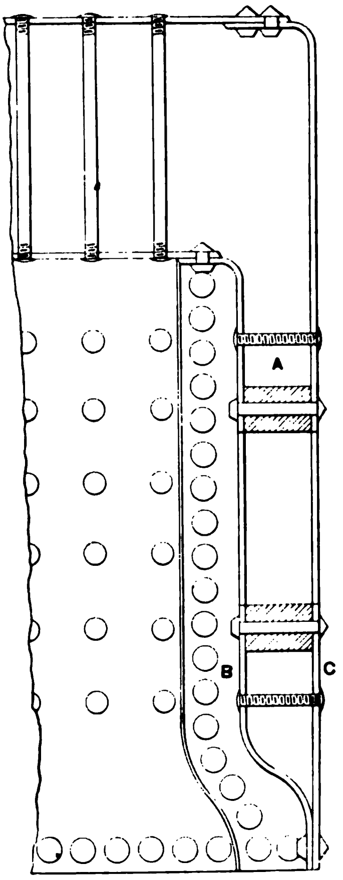


Fig. 17.

the two plates being riveted to the cast-iron ring. This form is better shown in Fig. 20. It makes this part of the boiler too rigid, but it has the advantage of not having rivet heads to wear off. In these methods of riveting, those which have the flanged ring are preferable to those using the cast-iron ring, because of more freedom for expansion; but the flanged ring forms an undesirable corner.

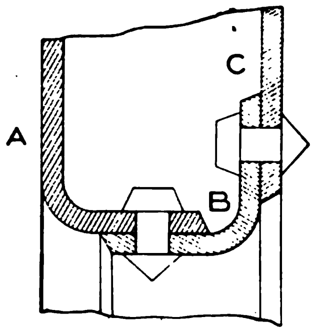


Fig. 19.

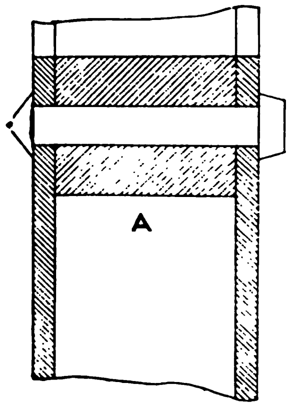


Fig. 20.

In almost every boiler, plates must be connected at right angles. An example of this is seen where the end plates are jointed to the shell plates of cylindrical boilers. There are three principal methods: riveting both plates to an angle iron, riveting to a flanged ring and flanging the end plate. In Fig. 21 the two plates are riveted to an angle iron, which is made of wrought or cast iron. This construction is too rigid; the constant variations of temperature cause repeated changes of form, which tend to crack the angle iron on the inside of the plate at the joint. Corrosion increases the evil, as it rapidly attacks iron which has once been cracked or broken. There is no definite rule for the dimensions of these angle irons, but it is safe to make the mean thickness a little greater than that of the plates.

The forms shown in Figs. 22 and 23 are better. The head is flanged and riveted to the shell plates. The flanging makes a more flexible joint. The radius of the curve of the flange should be about four times the thickness of the plate. The head and shell are sometimes connected to a flanged ring, as shown in Fig. 24. The extra row of rivets makes a complex joint.

In vertical boilers the external fire-box is joined to the cylindrical shell by riveted joints. Figs. 25 and 26 show two forms; that in Fig. 25 being the better on account of the flanged ring, which allows expansion and contraction of the shell and furnace plates.

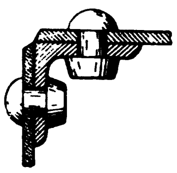


Fig. 21.

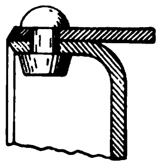


Fig. 22.

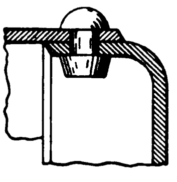


Fig. 23.

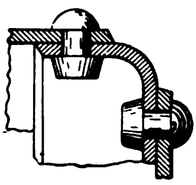


Fig. 24.

Sometimes the case occurs of connecting two plates which are parallel and near together. For instance, at the bottom of the locomotive fire-box a connection must be made between the inner and outer fire-box. The water-leg construction is a similar case. Several methods for this construction are shown in Fig. 27. Fig. 27A is too complicated and is undesirable, both on account of the numerous rivets and angle irons, and on account of the inside joints, which cannot be calked. Fig. 27B is better, since it has but one angle iron; it has, however, the undesirable inside joint.

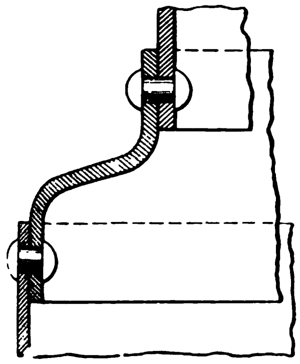


Fig. 25.

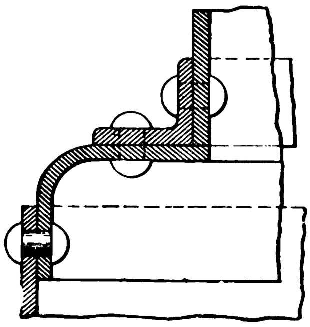


Fig. 26.

Fig. 27D is a good joint, the form of connection being called a channel iron. Fig. 27E, as we have seen, is a good flexible joint, but it has the undesirable corner where sediment lodges.

We have thus briefly discussed the various methods and arrangements for putting shells together, and now let us return to our boiler, which is ready for riveting at the hydraulic riveter. A few rivets are first driven at equal intervals around the ring seam at the back head. The reason for driving only a few rivets is that any errors in the spacing of the holes are distributed and not accumulated, as would be the case if they were driven in succession. From this point on, the riveting is continued until the shell is completely riveted up.

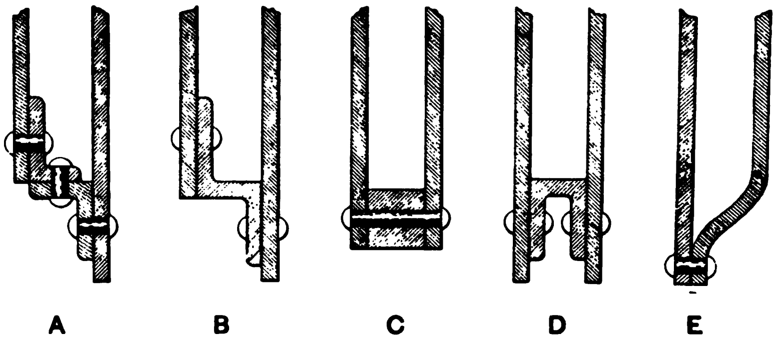


Fig. 27.

STAYING.

The shell is now ready to receive the stays. When under steam, a cylindrical shell is strained by internal pressure in two directions, namely: transversely, by a circumferential strain due to the pressure tending to burst the shell by enlarging its circumference, and longitudinally, by the pressure on the ends. If a boiler were spherical it would require no stays, because a sphere subjected to internal pressure tends to enlarge but not to change its shape. All flat surfaces in boilers must be stayed, otherwise the internal pressure would bulge them out and tend to make them spherical in shape. The ends of steam drums on high-pressure water-tube boilers are often made hemispherical.

The first and most important point in staying is to have a sufficient number of stays so that they will entirely support the plate without regard to its own stiffness. The second is to have them so placed as to present the least obstruction to a free inspection, and third, to have them so arranged as to allow a free circulation of water. Too much care cannot be taken in fitting stays and braces, as they are out of sight for long periods, and a knowledge of their exact condition is not always easily obtained. In the ordinary fire-tube boiler the principal surfaces stayed are: the flat ends, crown sheets, flat sides of locomotive boilers and combustion chambers of cylindrical marine boilers. In the case of most marine or Scotch boilers, the diameter is large compared to the length; hence the flat surface is considerable, and needs careful staying. All the plates that are not cylindrical or hemispherical must be stayed. The details should be arranged for each boiler; a few general methods and cautions can, however, be given.

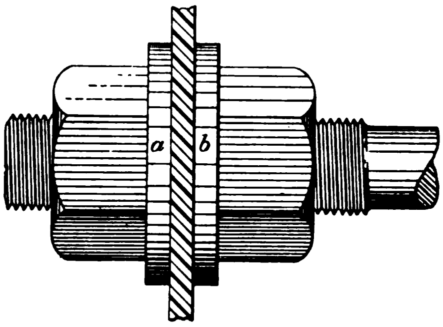


Fig. 28.

The most common and simple form of stay is a plain rod. It is used to stay the flat ends of short boilers. This stay is a plain rod passing through the steam space and having the ends fastened to the heads. The ends are fastened and the length adjusted in a variety of methods; the simplest being nuts on both sides of the plate, as shown in Fig. 28. The copper washers *a* and *b* strengthen the plate and prevent abrasion by the nuts. In place of the nuts the rod is often bolted to angle irons, which are riveted to the plates. In this case, turn buckles similar to the one shown in Fig. 29 are used for adjusting the length.

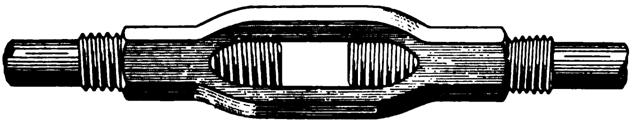


Fig. 29.

The stays are usually from $\frac{3}{4}$ inch to an inch in diameter, and are made of wrought iron or steel, with an allowable stress of 5,000 to 7,000 pounds per square inch. If the ends are fastened to riveted angle irons, the combined area of the rivets is made a little greater than that of the rod.

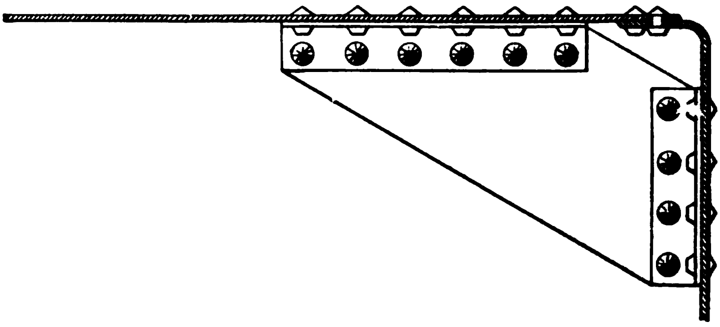


Fig. 30.

If a boiler is long, that is, more than 20 feet, long stays would sag in the middle and not take up the full stress on the end plates. For long boilers, gusset and diagonal stays are used. This form of boiler stay, shown, in Fig. 30, is made of wrought-iron plate riveted to angle irons; the angle irons being riveted to the end and shell. Boilers of the Cornish, Lancashire and Galloway types often have this kind of stay. These boilers are internally fired, and as the variation of temperature causes expansion and contraction, great care should be used in placing the gusset

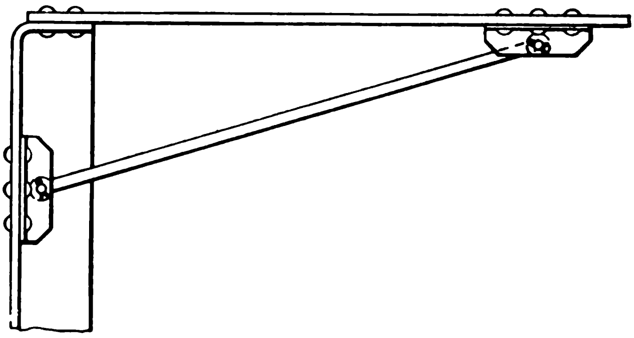
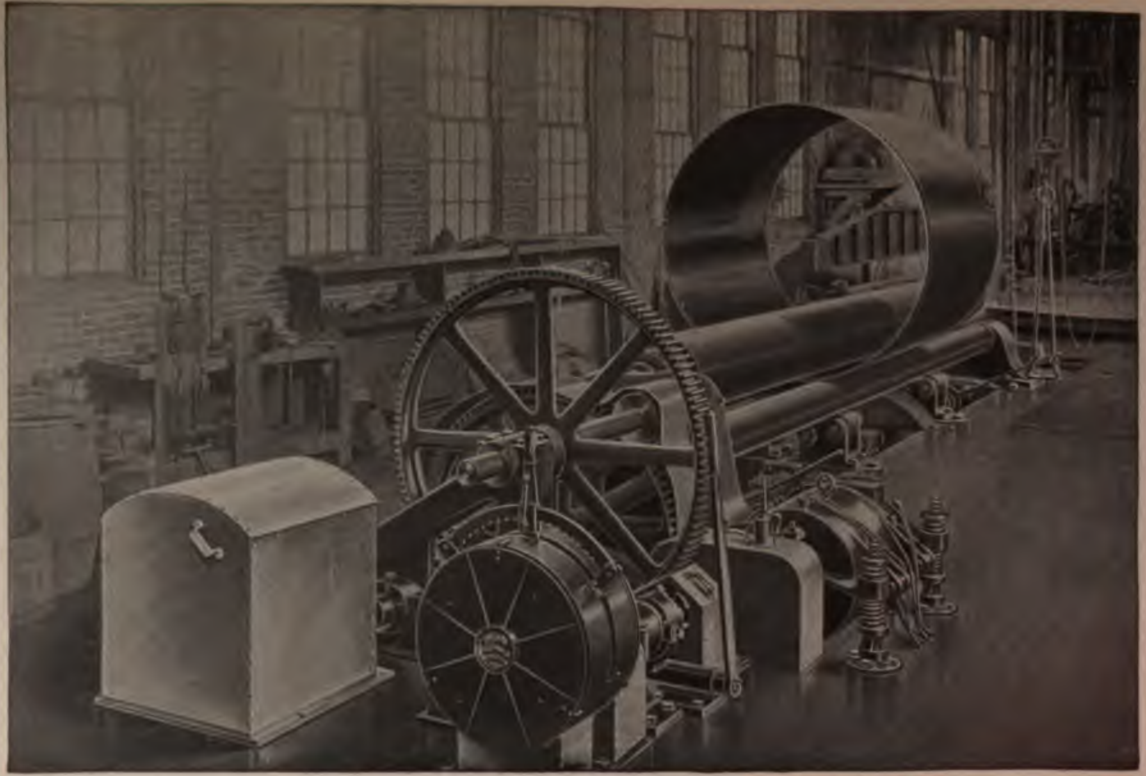


Fig. 31.



TWENTY-FOOT BENDING ROLLS.-CAHALL FACTORY.

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stay. If the stay is too near the flange or too many stays are used, the head will be too rigid and have a tendency to crack.

A form of diagonal stay is shown in Fig. 31. The plain rod is connected to angle irons by means of split pins. The angle irons are fastened to the shell and end by rivets or bolts. Another form of diagonal stay, called the crowfoot, is shown in Fig. 32. The two ends are bolted or riveted to the end and shell.

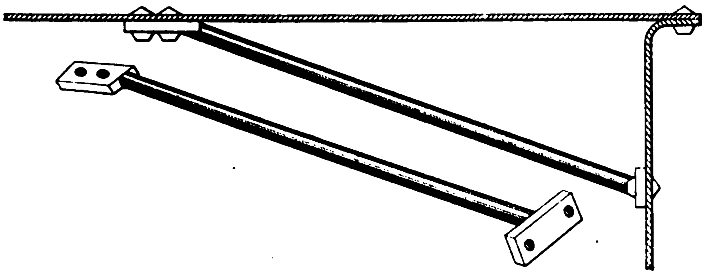


Fig. 32.

The angle between the shell plate and stay rod should be small,— not more than 30 degrees. The rod itself is designed for tensile strength, since the diagonal pull may be easily reduced to an equivalent direct pull. A large factor of safety is used to provide for future corrosion.

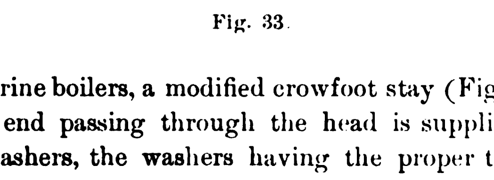


Fig. 33.

For marine boilers, a modified crowfoot stay (Fig. 33) is often used. The end passing through the head is supplied with nuts and taper washers, the washers having the proper taper to allow the nuts to be set up tightly against them.

In locomotive fire-boxes and in the combustion chamber of marine boilers, there are two flat or slightly curved surfaces that must be stayed together. These are riveted by short screw stay bolts. The bolts shown in Figs. 34 and 35 are screwed in place, and the ends riveted over. In marine boilers these stays are fastened with nuts, as shown in Fig. 36, instead of being riveted.

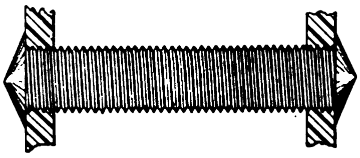


Fig. 34.

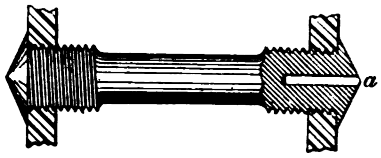


Fig. 35.

Sometimes the bolt is threaded the entire length, as in Fig. 34, or is turned off smooth in the center, as in Fig. 35. The smooth surface resists corrosion, and is less likely to fracture than the threaded bolt. Sometimes a small hole is drilled in the end, so that if the bolt breaks, the escaping steam will give warning. This is shown at *a*, Fig. 34. These bolts are $\frac{7}{8}$ inch or 1 inch in diameter.

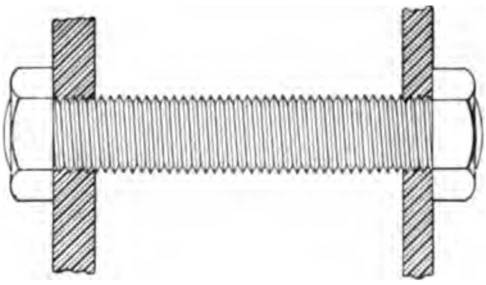


Fig. 36.

The strains which come on a stay bolt are not the same as those on rivets or on ordinary stay rods; as a matter of fact, stay bolts fail by a bending stress, and generally fracture just inside the outside sheet, due to the unequal expansion between combustion chamber or furnace and the outside boiler shell. Owing to this difference of expansion, flexible stay bolts have been designed, but have not come into general use, nor are they likely to, as they occupy considerable space and are much more complicated than the simple stay bolt. Stay bolts are made from the best quality of refined iron, which has been found to stand the strains of alternate heating and cooling better than mild steel. Iron stay bolts are more durable, because of the fibrous nature.

It should be added that boiler heads are further stiffened by channel bars or angles placed along the line of holes for the through stay rods.

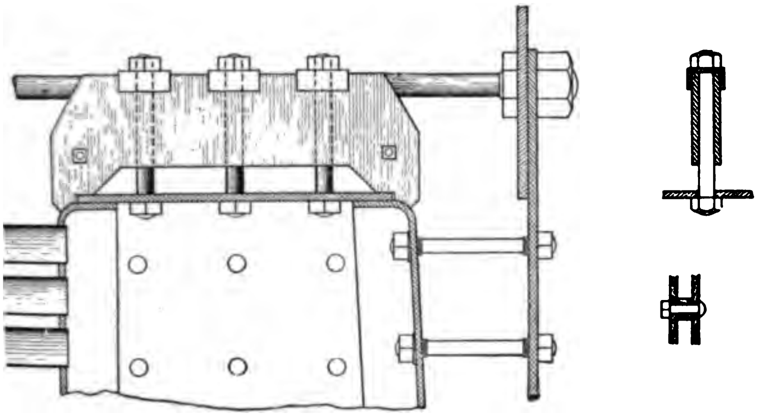


Fig. 37.

The crown sheets of fire-boxes and tops of combustion chambers are usually stayed by crown bars, which extend across the flat surfaces, as shown in Fig. 37, the ends resting on the

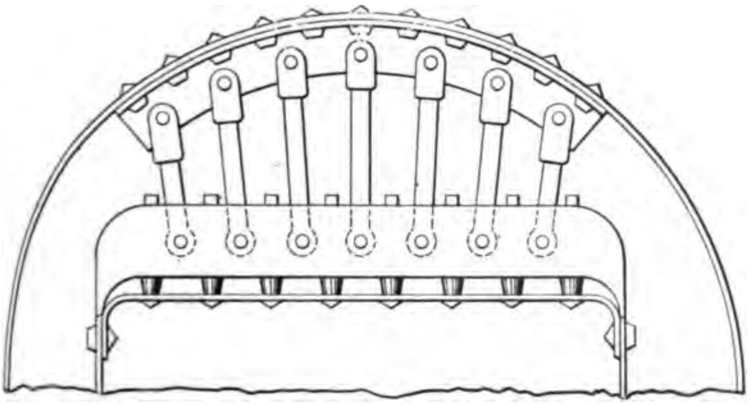


Fig. 38.

side plates. Bolts about 4 inches apart connect the crown sheet to this girder. The girder may be a solid bar, or it may be made up of two flat plates bolted or riveted together, as shown in the figure, the stay bolts being placed between the plates at intervals of about 4 inches. Either bolts or rivets may be used to keep the plates which form the girder from spreading. Projections are sometimes forged on the bottom of the girder, so that the stay bolts may be screwed up tightly without bending the plate.

The depth of the plates which make up the girder vary from 4 to 6 inches. They are from $\frac{5}{8}$ to $\frac{3}{4}$ inch in thickness. If bolts $\frac{7}{8}$ inch in diameter are used, the distance between the plates is usually 1 inch, but if larger bolts 1 inch in diameter are used, the distance should be $1\frac{1}{8}$ inches. The ends of the bars which rest upon the side plates should be carefully fitted to make a good bearing, and the area should be sufficient to prevent crushing of the end plates. The distance between the crown sheet and the girder should be at least $1\frac{1}{2}$ inches, so that there will be good circulation and the plates may be readily cleaned.

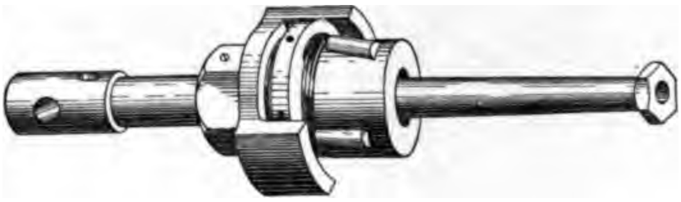


Fig. 39.

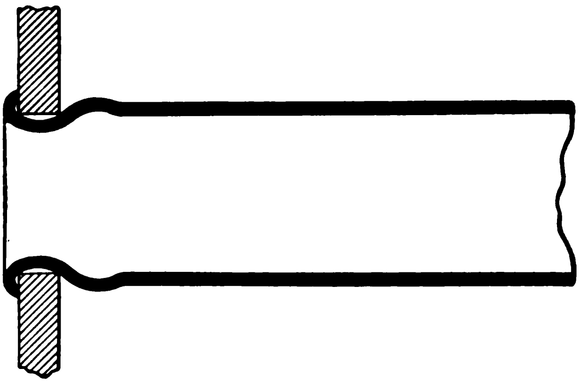


Fig. 40.

In some cases the girder is supported from the shell by sling stays, as shown in Fig. 38. The sling stays are connected to the girder and to an angle iron, or T-iron, which is riveted to the shell. The angle iron stiffens the shell. In designing this form of stay it is usual to make the girder strong enough to support the crown sheet without any sling stays, and these stays are used for additional support.

TUBES.

Boiler tubes are made of steel or wrought iron, but most commonly of charcoal iron and lap welded. In the formation of the lap the plate is upset, then bent around until the thickened edges lap sufficiently. It is then heated successively about 8 inches at a time, and welded over a mandrel, which is a cast-iron arm with a slightly convex top, over which the tube is placed Tubes are measured by their outside diameters, and are usually true to gauge, so that holes for them may be bored without taking measurements from the tubes themselves.

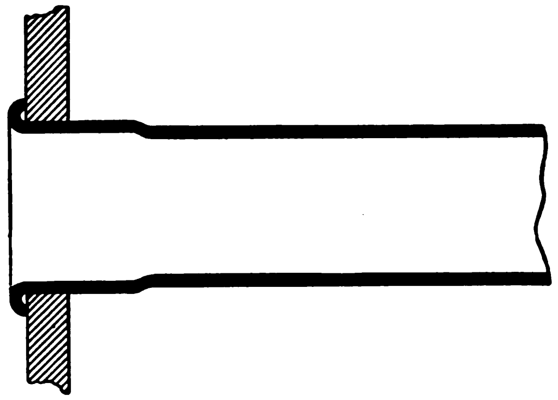


Fig. 41.

The holes for the tubes in the tube sheet are usually made in one of two ways. One method is to punch the tube holes the proper size by means of a helical punch. With this punch the metal is cut away by a shearing cut. The holes ought to be punched a little under size, and then reamed out, so that the surface against which the tubes are expanded may be good. The other method is to punch or drill a small hole at the point marking the center of the tube hole. A drill with a post in the center, which fits the small hole, then drills the desired size of hole.

Ordinary tubes are fastened to the end plates by expanding the metal of the tube against the tube plate. This is done by a tool called an expander, of which there are two common forms. One form consists of a steel taper pin and a number of steel segments, held in place by a spring. The outside of the segments have the form to be given to the expanded tube, and the inside is a straight hollow cone, into which the steel taper pin fits. The segments are forced apart by hammering on the steel pin. In order that the metal of the tube may not be injured, the hammering should be done gradually and carefully, and the expander turned frequently. Another form, shown in Fig. 39, has a set of rolls that are forced against the inside of the tube by driving in the taper pin. The pin and rolls rotate as the pin is driven, and the rolls gradually expand the tube against the tube plate.

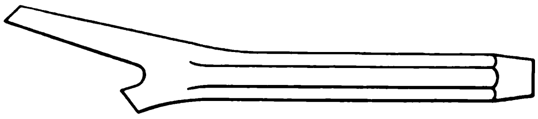


Fig. 42.

Two forms of tube expansion are shown in Figs. 40 and 41. That shown in Fig. 41 is preferable to that in Fig. 40, as the latter bears at the corners only, while the former bears against the entire thickness of the tube sheet.

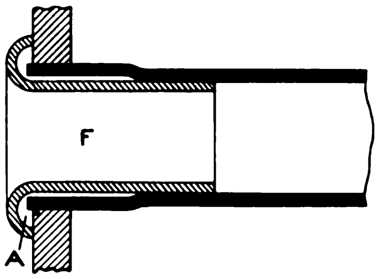


Fig. 43.

After the tubes are expanded, the ends are beaded over, as shown in Figs. 40 and 41. This adds to the strength of the connection between the tube and tube sheet. The tool commonly used for this beading is shown in Fig. 42.

Ferrules are often placed in the ends of fire tubes, and serve to protect the ends from the intense heat of the fire. The arrangement is shown in Fig. 43, the ferrule F being placed within the tube for a short distance. The space A is merely an air space.

Stay tubes are not used as extensively at the present time as they were formerly. They were very common at a time when the holding power of expanded tubes had been experimented on but little. It is now apparent from such tests that the holding power of tubes expanded, as shown in Fig. 40, is more than equal to the pressure on the spaces between the tubes of an ordinary tube plate. Stay tubes are simply heavier tubes, with the ends projecting beyond the tube sheet and threaded for shallow nuts. The ends of the tubes are frequently upset or thickened, and screwed into the tube sheet as well. This form is shown in Fig. 44.

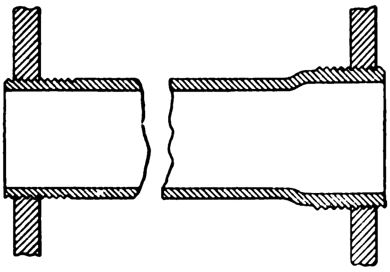


Fig. 44.

FURNACE FLUES.

Flues which are subjected to external pressure should always be cylindrical. Fig. 45 shows the section of the Adamson flue. This was an improvement over the plain furnace, as it is more elastic and allows expansion; the flanged rings also strengthen and stiffen it against collapse. The methods of building furnaces shown in Figs. 46 and 47 are not considered as good as the Adamson arrangement. Fig. 46 is too rigid, and does not

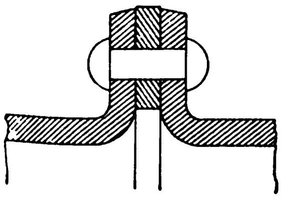


Fig. 45.

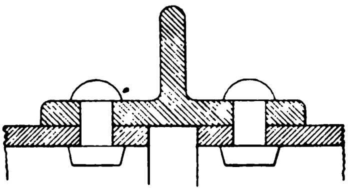


Fig. 46.

allow a free expansion and contraction. Fig. 47, on the other hand, permits of such extremely well, but both have the fault of exposing a double thickness of plates and two rows of rivets to the fire.

The corrugated flue shown in Fig. 48 is popular and, furthermore, is excellent. There is freedom for expansion throughout its whole length, thereby reducing the strains on the boiler.

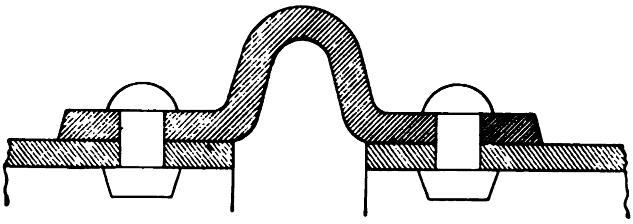


Fig. 47.

The plates should be thick enough to prevent sagging in the middle, the thickness usually varying from $\frac{5}{16}$ inch to $\frac{5}{8}$ inch. Corrugated furnaces are riveted to the rear tube sheet in the return tube boiler of the marine type, the end of the furnace being

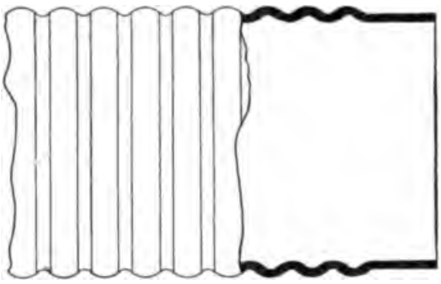


Fig. 48.

flanged at the front; and the head of the boiler is flanged around the opening cut for the furnace, which fits well into the flange.

CALKING.

In order that riveted joints of boilers may be steam and water tight, they generally require calking. This process upsets the metal of the overlapping plate, or burrs down the edge, forcing it into close contact with the lower plate, and rendering the joint steam tight.

The calking tool is similar to a chisel, the end having a variety of shapes. Fig. 49 shows a round-nosed tool which burrs down the upper plate without cutting the under plate; but it is hard to start, and in calking with such a tool the edge is first started with a sharper round-nosed tool, and then finished with one as indicated in the figure. If a square-end tool is used, as shown in Fig. 50, the under plate is likely to be cut, and the plates between the edge and the rivet be separated. The most common form of calking tool is one similar to the one shown in Fig. 49, except that the end is flat, with a slight bevel, and not round.

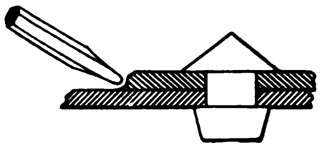


Fig. 49.

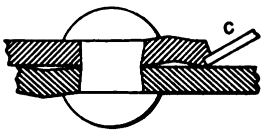


Fig. 50.

A slight bevel given the plates makes both calking and fullering more easily done. When the calking tool is thin it is sometimes driven by careless workmen into the joint, wedging the plates open. Severe and careless calking is very injurious to boilers. On the inside it often causes grooving and fracture, and the fracture of plates then follows the line of calking rather than the line of rivet holes. A pneumatic calking machine is often used in boiler shops, as it does this work about four times as rapidly as it can be done by hand. It resembles a rock drill in general principles. Air is supplied through a flexible tube, at a pressure of about 70 pounds per square inch. It makes about 1,500 strokes a minute.

BOILER DESIGN.

The rules of boiler design are controlled by practical consid-ations and theory, and are learned by the designer by practice nly. The rules vary from place to place, and from time to time, due to progress in engineering.

The rules, methods and cautions taken up here are general, and with necessary modifications can be applied to all the more common types.

In designing a steam boiler there are several considerations that must be kept in mind. Among the most important are strength, durability, capacity to furnish the required amount of steam, convenience for cleaning, repairing and inspection, simplicity in detail, and economy both of running and first cost.

The kind, or type, to be used depends upon the work to be done, the dryness of the steam, the locality, the available space and preference of the owner. The work to be done is determined by the number and kind of engines, the constancy with which they run and the pressure. In choosing a boiler for any locality, the purity of the water, the kind of fuel and the laws which govern inspection and allowable working stress must be considered. The available space greatly influences the type and sometimes prevents choice. For instance, locomotive and marine boilers must be put in a small space. For land boilers if the floor area is limited, but there is ample height, some type of vertical boiler must be chosen.

HORSE POWER.

The unit of horse-power as decided by the American Societ of Mechanical Engineers is equal to 33,305 B. T. U. From standard steam tables in treatises on Thermo-dynamics we that 966 B. T. U. are required to evaporate one pound of water fr and at 212° F. Therefore 1 H. P. is equal to the evaporation $33,305 \div 966 = 34\frac{1}{2}$ pounds of water from and at 212° F. This also equal to the evaporation of 30 pounds of water, at 100 into steam at 70 pounds gauge pressure.

The first thing to do is to chose the type of boiler we are Then we find how many pounds of steam are to be supplied is found by multiplying the desired horse-power

34½ or multiplying the horse-power of the engine or engines by the steam consumption per horse-power per hour. This is known approximately for every type of engine.

GENERAL REQUIREMENTS.

When we know these facts we design our boiler so as to have:

1. Sufficient area of grate to burn the required amount of fuel under the given draft.
2. Enough heating surface to absorb the heat of combustion.
3. Combustion chamber and flue area large enough to completely burn and carry off the products of combustion.
4. Water space sufficiently large so that a sudden demand will not cause too great a variation in water level.
5. Surface of water large compared to volume, in order that steam may be rapidly disengaged.
6. Steam space large enough to supply an irregular demand without causing a great change of pressure.
7. Steam outlet large enough to supply steam to the engine without wire-drawing.

If the outlet is not sufficiently large to supply plenty of steam, the demand will be greater than the supply and the steam will be throttled or wire-drawn, that is, it will lose some pressure.

For all common types of boilers, the proportions between the above requisites have been determined by experiment and mathematics. These relations, with simple calculations and good judgment on the part of the designer, are all that are needed for this work.

AREA OF GRATE.

A square foot of grate area will burn different weights of fuel in a given time, according to the nature of the draft. If the boiler can be made of any size, as is the case with many land boilers, a slow rate of combustion with natural draft is used, as it is the most economical. The length of the grate is limited by the distance to which a fireman can throw coal accurately. Usually 6 or 7 feet is the limit. In locomotive, torpedo boat and in some vertical land boilers, the size of grate is limited; in order to get the necessary work from the boiler, forceddraft is used and the rate of combustion increases to over 100 pounds per square foot per hour. In Lancashire boilers, with two internal flues, the breadth is limited. The rate of combustion is stated in pounds per square foot of grate area per hour, and varies with the type of boiler and the draft. The following table gives the rates of combustion.

CHIMNEY DRAFT.

Cornish boilers, slow rate	4—6 lbs. per sq. ft. per hour.
Cornish boilers, ordinary rate	10—15 lbs. per sq. ft. per hour.
Factory boilers, ordinary rate	12—18 lbs. per sq. ft. per hour.
Anthracite coal, quick rate	15—20 lbs. per sq. ft. per hour.
Bituminous coal, quick rate	20—30 lbs. per sq. ft. per hour.
Marine boilers, ordinary rate,	15—25 lbs. per sq. ft. per hour.
Water tube boilers	10—25 lbs. per sq. ft. per hour.

FORCED DRAFT.

Marine boilers,	60—130 lbs. per sq. ft. per hour.
Locomotive boilers,	40—120 lbs. per sq. ft. per hour.

The evaporation per square foot of grate surface depends upon the type, the rate of combustion, condition of boiler and care in firing. The highest rate is obtained with slow rate of combustion, care and skill in firing, and clean plates and tubes. The table gives the equivalent evaporation per pound of coal for several types.

Plain cylindrical	5-- 8 pounds.
Vertical	7—10 pounds.
Cornish	6—11 pounds.
Lancashire	6½-12 pounds.
Galloway	9—12½ pounds.
Multitubular	8—12 pounds.
Water tube	6 —12 pounds.
Marine return tube	7—12 pounds.
Locomotive	6—12 pounds.

Experiment shows that an increase in the amount of coal burned per square foot of grate per hour gives an increase in the amount of water evaporated; but a decrease in amount evaporated per pound of fuel, or a decrease in economy.

To find the area of grate for a boiler. Let G = area of grate in square feet, R = rate of combustion in pounds per square foot per hour, E = evaporation per pound of coal.

$$\text{Then } G = \frac{\text{Pounds of water evaporated}}{E \times R}$$

Let us take an example. Suppose we have an externally fired multitubular boiler; assume the rate of combustion to be 12 pounds, and that our type of boiler will evaporate 9 pounds of water per pound of coal. How large must the grate be, if 2400 pounds of water are evaporated per hour?

$$G = \frac{2400}{E \times R} = \frac{2400}{9 \times 12} = 22.2 \text{ square feet.}$$

Then 22.2 square feet of grate surface are necessary. In this case the grate probably would be made 6 feet by 4 feet or 24 square feet.

TUBES.

On account of the small number of successful experiments concerning flues and chimneys, it is usual to proportion tubes, flues and chimneys, by comparison with those that have given good results. If the tubes are too large the hot gases in the centre pass up the chimney at high temperature. Now we will find the number of tubes. Let A = total area in square feet through which the smoke passes, that is, the combined internal area of all the tubes. The total area of the tubes, A, is usually made $\frac{1}{6}$ to $\frac{1}{8}$ the area of the grate. If we design our boiler to have the ratio 1 : 8 we probably will have enough area. Let us assume our tubes to be 3 inches in diameter and 16 feet long. From the table, on page 40, of lap welded boiler tubes we find that the internal area of a 3 inch tube is 6.08 square inches, the internal circumference is 8.74 inches, external circumference is 9.42 inches, and the external area is 7.07 square inches. As $\frac{1}{8}$ of our grate surface is $\frac{24}{8}$ or 3 square feet, or 432 square inches, the number of tubes will be 432 ÷ 6.08 = 71.

LAP WELDED BOILER TUBES.

External Diameter. Inches.	Internal Diameter. Inches.	Thickness. Inches.	Internal Circumference. Inches.	External Circumference. Inches.	Internal Area. Square Inches.	External Area. Square Inches.	Length of tube per sq. ft. inside. Feet.	Length of tube per sq. ft. outside. Feet.	Weight per foot. Lbs.
1	.856	.072	2.689	3.142	.575	.785	4.460	3.819	.708
1¼	1.106	.072	3.474	3.927	.960	1.227	3.455	3.056	.900
1½	1.334	.083	4.191	4.712	1.396	1.767	2.863	2.547	1.25
1¾	1.560	.095	4.901	5.498	1.911	2.405	2.448	2.183	1.665
2	1.804	.098	5.667	6.283	2.556	3.142	2.118	1.909	1.981
2¼	2.054	.098	6.484	7.069	3.314	3.976	1.850	1.698	2.238
2½	2.283	.109	7.172	7.854	4.094	4.909	1.673	1.528	2.755
2¾	2.533	.109	7.957	8.639	5.039	5.940	1.508	1.390	3.045
3	2.783	.109	8.743	9.425	6.083	7.069	1.373	1.273	3.333
3¼	3.012	.119	9.462	10.210	7.125	8.296	1.268	1.175	3.958
3½	3.262	.119	10.248	10.995	8.357	9.621	1.171	1.091	4.272
3¾	3.512	.119	11.033	11.781	9.687	11.045	1.088	1.018	4.596
4	3.741	.130	11.753	12.566	10.992	12.566	1.023	.955	5.32
4½	4.241	.130	13.323	14.137	14.126	15.904	.901	.849	6.01
5	4.720	.140	14.818	15.708	17.497	19.635	.809	.764	7.226
6	5.699	.151	17.904	18.849	25.509	28.274	.670	.637	9.346
8	7.636	.182	23.989	25.132	45.795	50.265	.500	.478	15.109
10	9.573	.214	30.074	31.416	71.975	78.540	.399	.382	22.190
12	11.542	.229	36.260	37.699	103.749	113.097	.330	.318	28.516
16	15.458	.271	48.562	50.265	187.667	201.062	.247	.238	45.200
20	19.360	.320	60.821	62.832	294.373	314.159	.197	.190	66.765

STEAM SPACE.

The steam space is frequently designed as some fraction of the volume of the shell, usually about $\frac{1}{3}$. A better way is to design it from the steam consumption of the engine. Suppose the engine uses 30 pounds of steam at 75 pounds pressure per H. P. per hour. The absolute pressure then is 90 pounds (nearly) and the specific volume at that pressure is 4.85 (from steam tables). As steam is being generated at an approximately constant rate, the supply kept on hand need not be great. If the surface for the disengagement of steam is sufficient, the ratio of the steam space to the volume of the cylinder is from 50 : 1 to 150 : 1 depending upon the speed of the engine. Experiment shows that if the steam space is equal to the volume of steam consumed by the engine in 20 seconds, it is sufficient. If the space is only equal to the steam used in 12 seconds, there may be a considerable quantity of water carried over with the steam. If the engine is slow speed, that is less than 60 revolutions per minute, the steam space should be larger.

The volume of the steam space per H. P. will be the number of pounds of steam used per H. P. in 20 seconds, multiplied by its specific volume, or $\frac{30 \times 4.85 \times 20}{60 \times 60} = .81$ cubic feet (nearly) per H. P.; and if the engine is of 75 H. P. our steam space will be $.81 \times 75 = 60.75$ cubic feet.

TUBE SPACE.

The space occupied by the tubes is equal to their volumes. The volume of one tube is its external area multiplied by the length in inches. The total volume, in cubic inches, is the above result multiplied by the number of tubes. This is reduced to cubic feet by dividing by 1728. The space occupied by the tubes will be

$$\frac{71 \times 7.07 \times 16 \times 12}{1728} = 55.77 \text{ cubic feet.}$$

WATER SPACE.

Then if we assume our steam space to be $\frac{1}{3}$ the volume of the available space in the shell, the water space will be twice the steam space, or 2 × 60.75 = 121.5 cubic feet.

DIMENSIONS OF BOILER.

The volume of the boiler will be:

Steam space $.81 \times 75 =$ 60.75 cubic feet.

Tube space $\frac{71 \times 7.07 \times 16 \times 12}{1728} =$ 55.77 cubic feet.

Water space $.81 \times 75 \times 2 =$ 121.5 cubic feet.

Total space 238.02 cubic feet.

Since the tubes are 16 feet long the area of the end will be

$$\frac{238.02}{16} = 14.87 \text{ square feet.}$$

This area gives a diameter of about 4⅓ feet or 52 inches. We will make the boiler 4½ feet or 54 inches in diameter. Then the boiler will be 16 feet long and 54 inches in diameter; with 71 tubes 3 inches in diameter. For moderate power, a common rule is to make the length about 3½ times the diameter; by this rule our boiler is 3.55 times the diameter.

HEATING SURFACE.

The portion of a boiler that is exposed to the flames and hot gases is called the heating surface. This is made up of the portions of the shell below the brickwork, the exposed ends, and the internal surface of the tubes. If the boiler is of the water tube type, the exterior surface of the tubes is taken in place of the interior surface.

If our boiler is an ordinary multitubular boiler we can assume the heating surface to be the total inside area of the tubes plus one-half the area of the shell. Then:

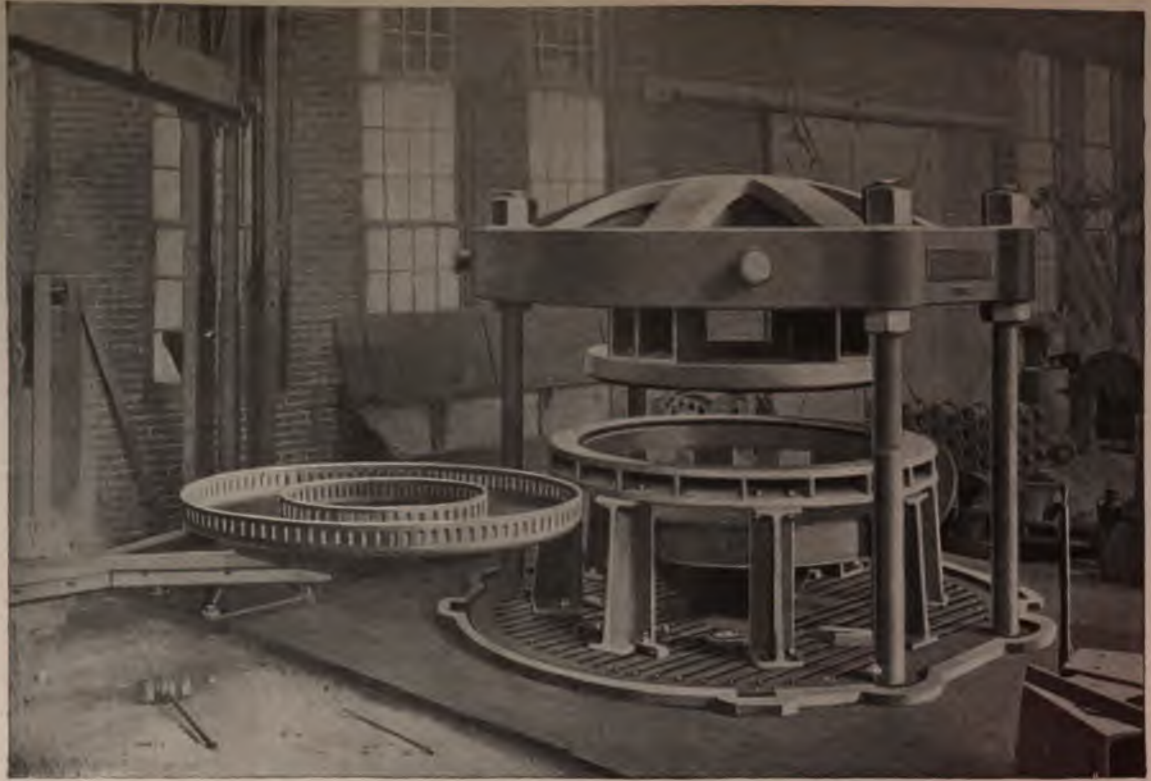
Heating surface of tubes $\frac{8.74 \times 71 \times 16}{12} =$ 827.38 square feet.

Heating surface of shell $\frac{14.137 \times 16}{2} =$ 113.10 square feet.

940.48 square feet.

The ratio of heating surface to grate surface will be

$$\frac{940.48}{24} = 39.2 \text{ or about } 39.$$



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As this ratio is high enough we will not alter our figures. If the ratio had been too low we could have added more tubes and found a new boiler diameter. The heating surface should not be less than 1 square yard or 9 square feet per horse-power. So 940.48 ÷ 75 = 12.54 or our boiler has 12.54 square feet of heating surface per horse-power. This is of course abundantly sufficient.

The capacity of heating surface to transmit heat to water depends upon conductivity, position of surface and temperature of furnace. In designing it is safe to follow proportions of heating surface to grate area in the various types, which experience has shown to give the best results. The following are the proportions for a few types.

Kind of Boiler.	Ratio of Heating Surface to Grate Surface.
Marine, Return tube,	25—38
Lancashire boiler,	26—33
Cornish,	27—32
Horizontal, internally fired,	40—50
Water tube,	34—65
Locomotive boiler (forced draft),	80—84
Marine,	28—32

RATIO OF GRATE SURFACE TO HORSE-POWER.

The ratio of grate surface to horse-power varies with the type, as is shown below.

Kind of Boiler.	Ratio.
Plain cylindrical,	.5 to .7
Multitubular,	.4 to .6
Vertical,	.6 to .7
Water tube,	.3
Lancashire,	.1 to .165
Marine return tube,	.12
Locomotives,	.02 to .06

Makers of boilers sometimes estimate the H. P. by the heating surface. That is the horse-power is a fraction of the heating surface. The ratio of heating surface to H. P. for several types is as follows:

Plain cylindrical,	6 —10
Multitubular,	14 —18
Vertical,	15 —20
Water tube,	10 —12
Marine return tube,	3.25— 4
Lancashire,	2.75— 4.25
Locomotive,	1 — 2

It is evident that some portions of the heating surface of a boiler have greater efficiencies than others. For instance, more heat will pass through the crown sheet as it is nearer the fire than through the last few feet of the tubes. Taking the efficiency of the crown sheet as 1, an estimate of the percentage of the other parts of a boiler is as follows:

Crown of furnace in flue,	.95
Plates of cylindrical boiler over furnace,	.90
Fire box tube plate of locomotive boiler,	.80
Water tube surface facing fire,	.70
Vertical side of fire box,	.50

If a cylindrical multitubular boiler is divided into equal sections, the section nearest the fire will evaporate more water than the one at the other end, as the gases have a higher temperature at the first section. Suppose we divide the boiler into six sections of equal length, and call the total evaporation 100 per cent. Then the per cent of evaporation per section will be approximately as follows:

Section	1	2	3	4	5	6
Evaporation	47	23	14	8	5	3

If the length of a boiler is increased another section, the evaporation will be increased a little but at the same time the radiating surface is increased. In case the addition of a section for evaporation causes a loss by radiation nearly equal to the gain in evaporation, it is not economical to add the section on account of the extra cost of the boiler. If forced draft or an increase of air of dilution is used, the boiler should be made longer to avoid waste. The air of dilution is the amount of air above that which is necessary to burn the coal.

WATER LEVEL.

If the steam space in a multitubular boiler is known the water level can be found, for the section of the steam space is a segment of a circle. In the above boiler the required steam space is 60.75 cubic feet; hence the segmental area is 60.75÷16 or 3.8 square feet, or 547.2 square inches. The height of this segment is 15.55 inches. This height is found either by calculation or from a table of segments. Then the mean water level is 15.55 inches from the top portion of the shell. The variation of water level in a boiler of this type and size should not exceed 6 inches.

END PLATE.

The end plate or tube sheet is usually made $\frac{1}{16}$ or $\frac{1}{8}$ inch thicker than the shell plates. This is done for additional stiffness, and increase of strength; the plate being weakened by drilling the holes for the ends of the tubes.

The tubes should be arranged in vertical and horizontal rows, if possible, in order that the rising bubbles of steam may not be hindered. To get good circulation the horizontal spaces should be a little greater than the vertical, and a central circulating space should be provided, if the necessary number of tubes can be put in without using the entire space. The tubes should be from $\frac{3}{4}$ to 1 inch apart, and to prevent burning of the tubes, the top row at least 3 inches below the water level, and the bottom tubes 6 inches from the shell. At this point, a drawing of the end plate should be made, to show the arrangement of tubes, etc. If it is impossible to put in the required number of tubes, without raising the water level, the diameter of the boiler must be increased. If we wish to increase the heating surface without increasing the diameter we can use smaller tubes or make the boiler a little longer.

STRENGTH OF BOILERS.

According to Pascal's Law, liquids and gases exert pressure equally in all directions. Steam in a boiler exerts the same pressure on all portions of the shell. As the pressure inside a boiler is considerably greater than that outside (the atmospheric pressure), there is a tendency to burst the shell. This tendency is resisted by the plates of the boiler.

A sphere is the strongest form to resist pressure, for since pressure is equal in all directions, there is a tendency towards enlarging the sphere and not to rupture. But a sphere has the smallest area for a given volume and, as a large heating surface is desirable, and on account of mechanical difficulties, a spherical boiler is never used. The boiler is made cylindrical to obtain greater heating surface and the loss in strength is made up by staying.

In the consideration of the strength of cylinders it is usual to divide the rupturing strains into two classes; those which tend to rupture the cylinder longitudinally and those which tend to rupture it circumferentially or transversely.

Let us examine them separately. The tendency to cause longitudinal rupture or to rend the cylinder in lines parallel with the axis, may be considered as the pressure exerted on a semi-circumference, and tending to rupture the cylinder in a plane through the diameter. Since pressure acts equally in all directions, the whole amount exerted on a semi-circumference is not exerted directly upwards and downwards. But all these forces may be resolved into their vertical and horizontal components. If we take the plane as horizontal, it is evident that the horizontal components have no tensional effect at the points of rupture. By taking the vertical components at an infinite number of points it can be proved that their sum is equal to the full pressure exerted on a rectangular plane equal to the projection of the cylindrical surface. In this case the projection is the plane through the diameter and has an area equal to the product of the length of the cylinder multiplied by the diameter of the cylinder. Then the force tending to rupture would be the pressure per square inch multiplied by the area. Let p = pressure in pounds per square inch, D = diameter of boiler, t = thickness of plate, L = length of boiler, S = tensile strength, E = efficiency of joint, and f = factor of safety. The force tending to rupture longitudinally will be, pLD. The strength of the cylinder to resist this rupturing force is represented by the tensile strength of the material multiplied by the areas of sections of metal. Or expressed algebraically is 2tLS. When rupture is about to take place the rupturing force and the strength are equal, or

$$pDL = 2tLS \quad \text{or} \quad pD = 2tS$$

from which $p = \frac{2\,t\,S}{D}$ and $t = \frac{pD}{2S}$ which are the formulas for pressure and thickness and for longitudinal strength.

The extra pressure due to increased length is balanced by the increase of metal as is shown by the elimination of the factor L of the equation.

The tendency to rupture circumferentially is evidently represented by the area of the end or $\frac{\pi\,D^2}{4}$ multiplied by the pressure per square inch. The strength to resist this force is the area of metal to be ruptured multiplied by the tensile strength or $\pi\,DtS$

$$\frac{\pi\,D^2}{4} \times p = \pi\,DtS$$

$$Dp = 4tS$$

By comparing these two formulas we see that with the same internal pressure, diameter and thickness of shell, a cylindrical boiler is twice as strong transversely as it is longitudinally, hence the greatest tendency to rupture is usually, but not always, along the longitudinal seams.

Therefore, in designing the thickness of shell we use the formula for longitudinal rupture,

$$pD = 2tS \text{ or } t = \frac{pD}{2S}$$

or, inserting the factors for efficiency of joint and factor of safety,

$$pD = \frac{2tSE}{f}$$

For allowable pressure $p = \frac{2tSE}{fD}$

For thickness of shell $t = \frac{fDp}{2SE}$

Now let us find the thickness of the boiler that we are designing. Suppose after testing our material we find that its ultimate tensile strength is 54,000 pounds per square inch. In this case 6 will be sufficiently large for a factor of safety. This factor can be reduced if the efficiency of the joint is large. Let us assume that our joint has an efficiency of 70%. This is merely a supposition because we have not yet constructed the joint; but we assume a factor in order to find a trial thickness.

$$\text{Then } t = \frac{fDp}{2SE} = \frac{6 \times 54 \times 75}{2 \times 54000 \times .7} = .32 \text{ or about } \tfrac{5}{16} \text{ inches.}$$

RIVETED JOINTS.

The best knowledge of the strength and proportions of riveted joints can be obtained by tests of full sized pieces. Let us consider the strength and efficiency mathematically. Riveted joints may fail in several ways. 1. By shearing the rivets. 2. By tearing the plate at the reduced section between the rivets. 3. By crushing the plate or rivets where they are in contact. 4. By cracking the plate between the rivet hole and the edge of the plate. As the lap in practice can always be made sufficiently wide a joint need never fail in this last way.

As all stresses may be resolved into the three kinds, tensile, compressive and shearing, we will investigate for these stresses. Let P = the tensile stress transmitted from one plate to the other by a single rivet, t = the thickness of the plate, d = the diameter of the rivet, p = the pitch, and S_t, S_s and S_c the unit stresses in tension, shear and compression respectively produced by P on the plates and rivets. Therefore the tension on the plate, P will be equal to the area of the metal between the rivets multiplied by its unit tensile stress, or

$$P = t\,(p - d)\,S_t$$

For shear, P will equal the area of the rivet multiplied by the unit shearing stress, or

$$P = \tfrac{1}{4}\,\pi\,d^2 S_s$$

For compression, the stress is supposed to be equivalent to a stress uniformly distributed over the projection of the cylindrical surface on a plane through the axis of the rivet. Then P will be equal to the area of the projection multiplied by the unit compressive stress, or

$$P = tdS_c$$

The above formulas are for single riveted lap joints. If another row of rivets is used the plates should have a wider lap. Let $p =$ the pitch in one row; then the stress will be distributed over two rivets.

The three formulas in this case will be.

$$P = t\,(p - d)\,S_t$$
$$P = 2 \times \tfrac{1}{4}\pi d^2 S_s$$
$$P = 2\,tdS_c$$

For single riveted butt joint, the shear comes on two rivets; this is called double shear. The above formulas become

$$P = t\,(p - d)\,S_t$$
$$P = 2 \times \tfrac{1}{4}\pi d^2 S_s$$
$$P = tdS_c$$

The efficiency of a joint is the ratio of its allowable stress to the allowable stress of the uncut plate. The allowable stress of the plate is represented by the formula ptS_t.

Then the efficiency for tension is, $E = \dfrac{t\,(p - d)\,S_t}{ptS_t} = \dfrac{p - d}{p}$

For shear, $E = \dfrac{\frac{1}{4}\pi d^2 S_s}{ptS_t}$ or $\dfrac{\frac{1}{4}\pi d^2 S_s c}{ptS_t}$

For compression, $E = \dfrac{tdS_c}{ptS_t}$ or $\dfrac{dS_c}{pS_t}$ or $\dfrac{dS_c a}{pS_t}$

In the above formulas, $a =$ the number of rivets in the width p, and $c =$ the number of rivet sections in the same space. The smallest value of E is to be taken as the efficiency of the joint.

In designing, we try to get a joint in which all parts will have equal strength or the resistance of the plate to tension will equal the resistance of the rivets to shearing and each will equal the resistance of the rivet to compression or crushing. This will be the case if the three efficiencies are equal.

Solving for d in the second and third we get

$$\frac{\frac{1}{4}\pi d^2 S_s c}{ptS_t} = \frac{dS_c a}{pS_t} \text{ or } d = \frac{4\,aS_c t}{\pi c S_s}$$

If we know t we can find d from the above equation.

To find the pitch we make the first equation equal to the third, or the formula for tension equal that of compression, and solve for p

$$\frac{p-d}{p} = \frac{dS_c a}{pS_t},\ p = d\left(\frac{S_c a}{S_t} + 1\right)$$

substituting the value for d, obtained above,

$$p = \frac{4\ aS_c t}{\pi\ cS_s}\left(\frac{S_c a}{S_t} + 1\right)$$

To get the formula for efficiency we insert these values for d and p, in any of the formulas for efficiency already obtained. For instance:

$$E = \frac{p-d}{p} = \frac{\frac{4\ aS_c t}{\pi\ cS_s}\left(\frac{S_c a}{S_t} + 1\right) - \frac{4\ aS_c t}{\pi\ cS_s}}{\frac{4\ aS_c t}{\pi\ cS_s}\left(\frac{S_c a}{S_t} + 1\right)}$$

$$E = \frac{1}{1 + \frac{S_t}{aS_c}}$$

A good joint can be designed without these formulas (in fact they serve as a guide only), if attention is paid to the rules deduced from tests and conforming to good practice by experienced engineers and boiler makers. In designing a riveted joint, good practice favors the following:

The pitch of rivets, for single riveting, should be about 2½ times the diameter of the rivets and for double riveting about 3¾ times the diameter.

The pitch near a calked edge must not be too great for proper calking.

Rivets must not be too near together.

The lap, or the distance from the centre of the rivet to the edge of the over-lapping plate should be at least 1½ times the diameter of the rivet.

The diameter of the rivet is usually nearly twice the thickness of the plate and should never be less than the thickness of the plate.

The riveted seam must contain a whole number of rivets. and similar seams should have the same pitch.

The distance between rows, for double riveting, is about twice the diameter of the rivets.

In double butt riveting the rivets in double shear have $1\frac{3}{4}$ times the single section instead of 2.

The thickness of double butt straps should not be less than $\frac{5}{8}$ the thickness of the plate (each); single butt straps not less than $\frac{9}{8}$.

No one set of rules can be laid down for the best pitch of rivets for all circumstances of pressure, quality of plates, etc. The following table of proportions of riveted joints gives results for average practice in boilers of up to about 150 pounds pressure.

TABLE OF LAP JOINTS.

Thickness of Plate. Inches.	Diameter of Rivet. Inches.	Diameter of Hole. Inches.	Pitch. Inches.		Efficiency.	
			Single Riveted.	Double Riveted.	Single Riveted.	Double Riveted.
$\frac{1}{4}$	$\frac{5}{8}$	$\frac{11}{16}$	2	3	.66	.77
$\frac{5}{16}$	$\frac{11}{16}$	$\frac{3}{4}$	$2\frac{1}{16}$	$3\frac{1}{8}$	.64	.76
$\frac{3}{8}$	$\frac{3}{4}$	$\frac{13}{16}$	$2\frac{1}{8}$	$3\frac{1}{4}$	.62	.75
$\frac{7}{16}$	$\frac{13}{16}$	$\frac{7}{8}$	$2\frac{3}{16}$	$3\frac{3}{8}$	.60	.74
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{15}{16}$	$2\frac{1}{4}$	$3\frac{1}{2}$	.58	.73

As the stress on the transverse section is one-half that on a longitudinal section, a single or double lap joint is sufficient for any ring seam. For externally fired multitubular boilers with shell plates less than $\frac{1}{2}$ inch thick, single riveted ring seams are used. For our boiler, the plates being $\frac{5}{16}$ inch thick, we will use rivets $\frac{11}{16}$ inch in diameter, as this agrees with good practice. From the table, the pitch for a $\frac{11}{16}$ inch rivet for single riveted lap joint is $2\frac{1}{16}$. Then as our ring seam is $3.1416 \times 54 = 169.65$ inches and pitch $2\frac{1}{16}$ inches we will have 82 + rivets. But as we must have a whole number of rivets we will alter the pitch slightly and use 82 rivets with a pitch of 2.069 inches. The result depends, in each case, upon the kind of joint used in longitudinal seams. This merely shows the general method. The lap will be $\frac{11}{16} \times \frac{3}{2} = 1\frac{1}{32}$ inch.

For the longitudinal seams we will use double butt joints with single riveting. The thickness of the butt straps will be $\frac{5}{16} \times \frac{5}{8} = .20$ (nearly). To be on the safe side we will make the butt straps $\frac{1}{4}$ inch thick. The pitch for double butt joints is usually about 4 times the diameter of rivets, so in this case it will be $4 \times \frac{11}{16} = 2\frac{3}{4}$ inches. We will use the same amount of lap for this joint as for the lap joint, that is $1\frac{1}{32}$ inches.

SECTIONS.

The boiler is made up of rings or sections. The length of sections is often made equal, for convenience in ordering and cutting plates. The length is limited by the width of plate obtainable and the size of the riveting machine. This boiler being 16 feet long would probably be made in three sections, but the lengths should be so adjusted as not to bring the ring seam over the hottest part of the fire.

FLUES.

The internal pressure at which the boiler shell will rupture can be calculated; but the external pressure which will collapse a flue can be determined only by experiment. External pressure tends to increase any imperfection of shape. For instance, if a flue is slightly oval, the external pressure tends to make it more flat. The strongest form to resist external pressure is evidently the circle. When considering the strength of flues length is very important.

If a lap joint is used the flue will not be a true cylinder, for this reason welded or butt joints are preferable.

Fairbain gives the formula, $P = \frac{806{,}000\, t^{2.19}}{ld}$ for calculating the collapsing pressure of flues, l = length of flue in feet, d = diameter in inches, t = the thickness in inches, P = pressure per square inch. The exponent of t is often taken as 2 instead of 2.19 for convenience. This formula is empirical and was prepared from his experiments.

Hutton gives, $P = \frac{C\, t^2}{d \sqrt{L}}$. In which C is a constant, which is 600 for wrought iron and 660 for mild steel, L = length in inches, d = external diameter in inches, and t = thickness in *thirty-seconds* of an inch. Results by Hutton's formula agree more nearly to those by experiment than do Fairbain's.

If the flues are oval, d in the above formula = the major axis.

Flues are strengthened by putting in hoops at stated distances. These hoops are made of T iron or angle iron.

TUBES.

The materials for tubes are iron and steel. The tubes must be tough to resist cutting by cinders. If iron is used it should have a tensile strength of at least 45,000 pounds per square inch, with an elongation of 15 to 20 per cent. If steel, the elongation should not be less than 26 per cent, when tested before being rolled. If the steel welds well there need not be any limit to its tensile strength. The ends of tubes should be annealed after manufacture. The thickness of tubes is always greater than that required to prevent collapsing, in order to weld and expand in the tube sheet. It is often desirable to use part of the tubes as stays; for this purpose the tubes are made thick enough to take a shallow nut outside the tube plate.

STAYING.

As large a portion as possible of the shell of a boiler is made cylindrical, for in this form plates can be made sufficiently strong without the aid of stays or braces. But all flat surfaces must be stayed; not only to prevent rupture, but also to provide against distortion and grooving. The theoretical investigation of the strength of flat surfaces, can be worked out only with higher mathematics. From the formula deduced, the solid end plate would have to be about 2 inches thick for a boiler only 3 feet in diameter with plates $\frac{3}{8}$ inch thick. It is evident that the flat ends if of ordinary thickness must be strengthened by stays or braces. The calculation of stresses in a flat plate, supported by stays, can be calculated only when the supported points are in rows thus dividing the surface into equal squares. Even when the stays are not to be placed in rows forming squares, it is well to make the calculation for a standard.

The equation for finding the area supported by a stay rod is,

$$a^2 = \frac{9t^2S}{2p}$$

in which a^2 = the area supported, t = the thickness of the end plate, S = the allowable stress on the area of the rod, and p = the working steam pressure. Let us find the area supported in our multitubular boiler. In order to provide for future corrosion we will use a factor of safety of 12 and assume, in the absence of exact knowledge, the ultimate breaking strength of the rod to be 60,000 pounds per square inch. It is usual to make the diameter of the rods one to two inches, so we will make ours $1\frac{1}{2}$ inches in diameter with an area of 1.767 square inches. Then the stress per rod is 5,000 × 1.767 = 8,835 pounds.

$$a^2 = \frac{9t^2S}{2p} = \frac{9 \times \frac{1}{4} \times 8{,}835}{2 \times 75} = 132.5 \text{ square inches.}$$

Then as the rod supports 132.5 square inches and the segment of the steam space is 547.2 square inches, the number of rods will be $\frac{547 \cdot 2}{132 \cdot 5} = 4$.

The same formula will apply in finding the number of short screw stay bolts of the fire box.

Suppose we wish to use a diagonal or crow foot stay, making an angle of 20° with the shell. If the rod is 1 inch in diameter and the stress is limited to 7,000 pounds, then it will carry a pull of .7854 × 7,000 = 5497.8 pounds, and since it makes an angle of 20°, the pull perpendicular to the head will be 5497.8 × cos. 20° = 5497.8 × .9397* = 5,166 pounds. If the end is fastened by two rivets or bolts each will carry 2,583 pounds. If each rivet or bolt supports a square with a side equal to a, then 5,166 = 75 a^2

$$a^2 = \frac{5166}{75} = 68.9 \text{ square inches (nearly).}$$

UPTAKE.

The area of the uptake, like the area of the tubes, is made about $\frac{1}{7}$ to $\frac{1}{8}$ of the area of the grate. We find that $\frac{1}{8}$ of the grate surface is 432 square inches. If we make the uptake 12 inches deep measured with the length of the boiler, it will be 432 ÷ 12

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* **NOTE.** Taken from a table of cosines.

= 36 inches wide. The opening of the shell at the front end will be 12 inches deep and the plate cut down until it is 36 inches wide.

MANHOLES.

The manhole and handhole should be strong enough and stiff enough to sustain the stresses due to the direct steam pressure and from the stresses of the plates. The calculation of the strength of the manhole ring is difficult and the results obtained very uncertain, so they are made of forms and dimensions that have been used in good practice and given good results. These fittings are bought in steel forgings. Boiler makers design the forged rings which lie close to the shell, of a section at least equal to the section of the plate that is cut out. The bearing surfaces of the manhole cover and that of the lip against which the cover bears, should be machined to make a good smooth joint. The joints are made tight by gaskets about $\frac{3}{4}$ of an inch wide.

Hand holes are constructed similarly to manholes, and often have a taper key in place of a bolt and nut, because the nut is exposed to fire and after it has been in place some time, is often difficult to remove with a wrench.

BRACKETS.

Boilers of the multitubular types are supported by brackets usually made of cast iron. Boilers up to 16 feet long have four brackets and those more than 16 feet long have six brackets. The brackets for this boiler should be about 10 inches long, measured with the length of the boiler, and about 15 inches wide. They are riveted to the boiler with nine or ten rivets $\frac{7}{8}$ to 1 inch in diameter. The rivets can be made large, as a large rivet makes a strong joint, and in this case the pitch is not governed by calking.

The load on the brackets can be estimated by calculating the weight of the boiler full of water and adding the weight of all the parts supported by the boiler. These parts include pipes, valves, gauges, brickwork covering, etc. This load should be divided as nearly equal as possible among the four brackets, so that the tendency of the boiler toward bending shall be small.

Brackets are set above the middle line of the boiler in order that the flanges may be protected by the brickwork setting. They are usually 3 or 4 inches above the middle.

CHIMNEYS.

At the present time, the knowledge of chimneys and chimney draft is slight. The theories given are worth but little as they are based upon data which is entirely insufficient. As to the design and proportions of chimneys, there are no systematic statements and rules that can be used.

Chimneys are usually designed from empirical formulas and from tables, compiled from proportions of chimneys that have furnished sufficient draft, etc.

The draft produced in a chimney is due to the difference in temperature, and consequently difference in pressure, between the gases inside the chimney, and the air outside. The gases in the chimney being lighter rise toward the top and air rushes in at the bottom to fill the space left by the hot gases. This air as it becomes heated grows lighter and rises, thus a continuous circulation is kept up. The temperature of the gases in the chimney is considered to be about 600° F. for chimney calculation, as practice shows this to give good draft under economical conditions.

After making several assumptions, based on experiments, the following formula has been deduced:

$$\text{H. P.} = 3.33\,(A - .6\sqrt{A})\sqrt{h}$$

in which H. P. = horse-power, A = area of the chimney, and h = the height above the grate.

The following table on page 46 has been calculated from this formula. This table is used to a considerable extent with satisfactory results.

The part of the table which is used for ordinary proportions is filled in. If proportions are taken from the table rather than from the formula, the results will give better proportions.

To find the area of the top of the chimney for a given coal consumption, the following empirical formula has been stated.

$$A = \frac{\text{H. P.} \times B \times 12}{\sqrt{h}}$$

in which A = area, H. P. = horse-power of boiler, B = number of pounds consumed per H. P. per hour and h = height of chimney in feet.

This area A is the area in square inches at the top.

Diameter, in Inches.	Height of Chimneys and Commercial Horse-power.											Side of square in inches.	Effective area, square feet.	Actual area, square feet.
	50 ft.	60 ft.	70 ft.	80 ft.	90 ft.	100 ft.	110 ft.	125 ft.	150 ft	175 ft.	200 ft.			
18	23	25	27									16	0.97	1.77
21	35	38	41									19	1.47	2.41
24	49	54	58	62								22	2 08	3.14
27	65	72	78	83								24	2.78	3.98
30	84	92	100	107	113							27	3.58	4.91
33		115	125	133	141							30	4.48	5.94
36		141	152	161	173	182						32	5.47	7.07
39			183	196	208	219						35	6.57	8.30
42			216	231	245	258	271					38	7.76	9.62
48				311	330	348	365	389				43	10.44	12.57
54					427	449	472	503	551			48	13.51	15.90
60					536	565	593	632	692	748		54	16.98	19.64
66						694	728	776	849	918	981	59	20.83	23.76
72						835	876	934	1023	1105	1181	64	25.08	28.27
78							1038	1107	1212	1310	1400	70	29.73	33.18
84							1214	1294	1418	1531	1637	75	34.76	38.48
90								1496	1639	1770	1893	80	40.19	44.18
96									1876	2027	2167	86	46.01	50.27

Another method which is much more simple is to design the area of the chimney, as we have designed the total tube area; that is, about $\frac{1}{8}$ the grate area. This ratio for chimneys is sometimes about $\frac{1}{7}$ and decreases to $\frac{1}{9}$ and for very tall chimneys to $\frac{1}{10}$.

From the table we find the chimney to have an area at the top of about 3.98 square feet, assuming it to be 60 or 70 feet high. This area gives a diameter of 27 inches if circular, or 24 inches if square.

Let us calculate it from the formula $A = \frac{\text{H. P.} \times B \times 12}{\sqrt{h}}$

We must either assume or calculate B. As the calculation is very easy it would be better than any assumption. The total amount of coal burned per hour equals 12 × 24 or 288 pounds. The amount per H. P. per hour is 288 ÷ 75 or 3.84 pounds.

Then assuming the chimney to be 60 feet high,

$$A = \frac{75 \times 3.84 \times 12}{\sqrt{60}} = 446$$ square inches, or about 24 inches in diameter if circular and 21 inches if square.

By the last method the area of the chimney will be 24 ÷ 8 or 3 square feet, or 432 square inches, giving practically the same result as with the formula.

As the table is reliable and gives us the larger area, we will use it and be on the safe side; also as the amount of coal burned per hour by the draft in a chimney can be found by multiplying the horse-power in the above table by 5, the chimney with an area of 3.98 square feet and 60 feet high will burn 72 × 5 = 360 pounds of coal per hour. The boiler in question burns only 288 pounds, so the chimney is sufficiently large.

Chimneys are usually of brick or of steel plates. If of steel they are always circular. When made of brick they are circular, square or hexagonal. With a given draft area, a circular chimney requires the least material, since a circumference has the least perimeter for a given area; it also presents less resistance to wind.

A steel chimney is made up of plates of steel riveted together. The shell is bolted through a foundation ring of cast iron to the stone foundation. It has a straight taper to the top, which is finished, for appearance with light plates. The shell is lined with fire-brick, with a thickness which varies from 12 to 18 inches at the bottom to about 2 to 4 inches at the top. This lining is used to prevent heat being lost from the shell and does not add to the strength of the chimney.

A brick chimney is built in two parts; *a* the outer shell, which resists wind pressure and *b*, the lining which is the flue. This flue is made separate from the external shell in order that it may expand, when the chimney is full of hot gases, without straining the outer shell.

The interior of both steel and brick chimneys are often cylindrical while the exterior tapers. The taper is about .3 inch to the foot. The brick at the base of the chimney is splayed out to make a large base.

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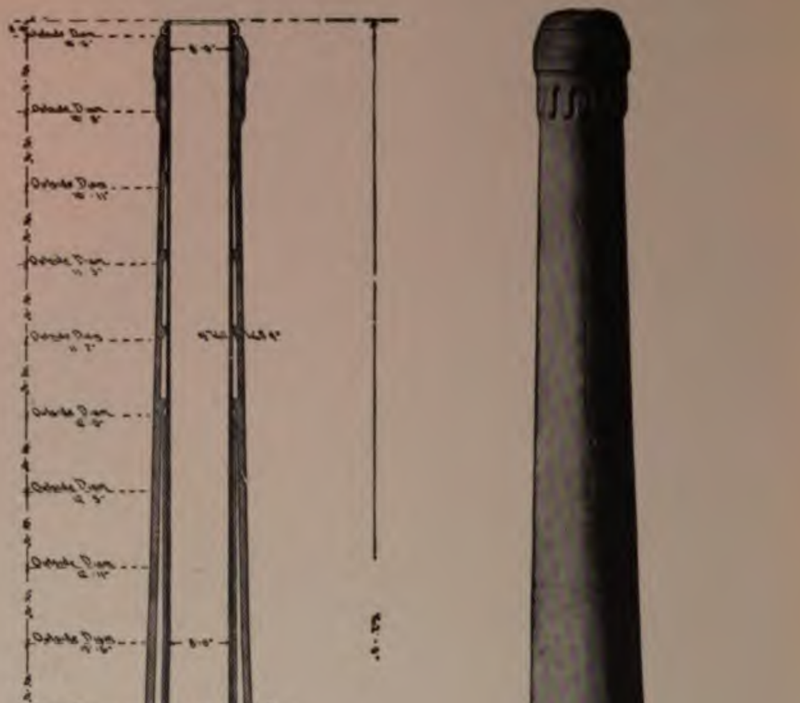
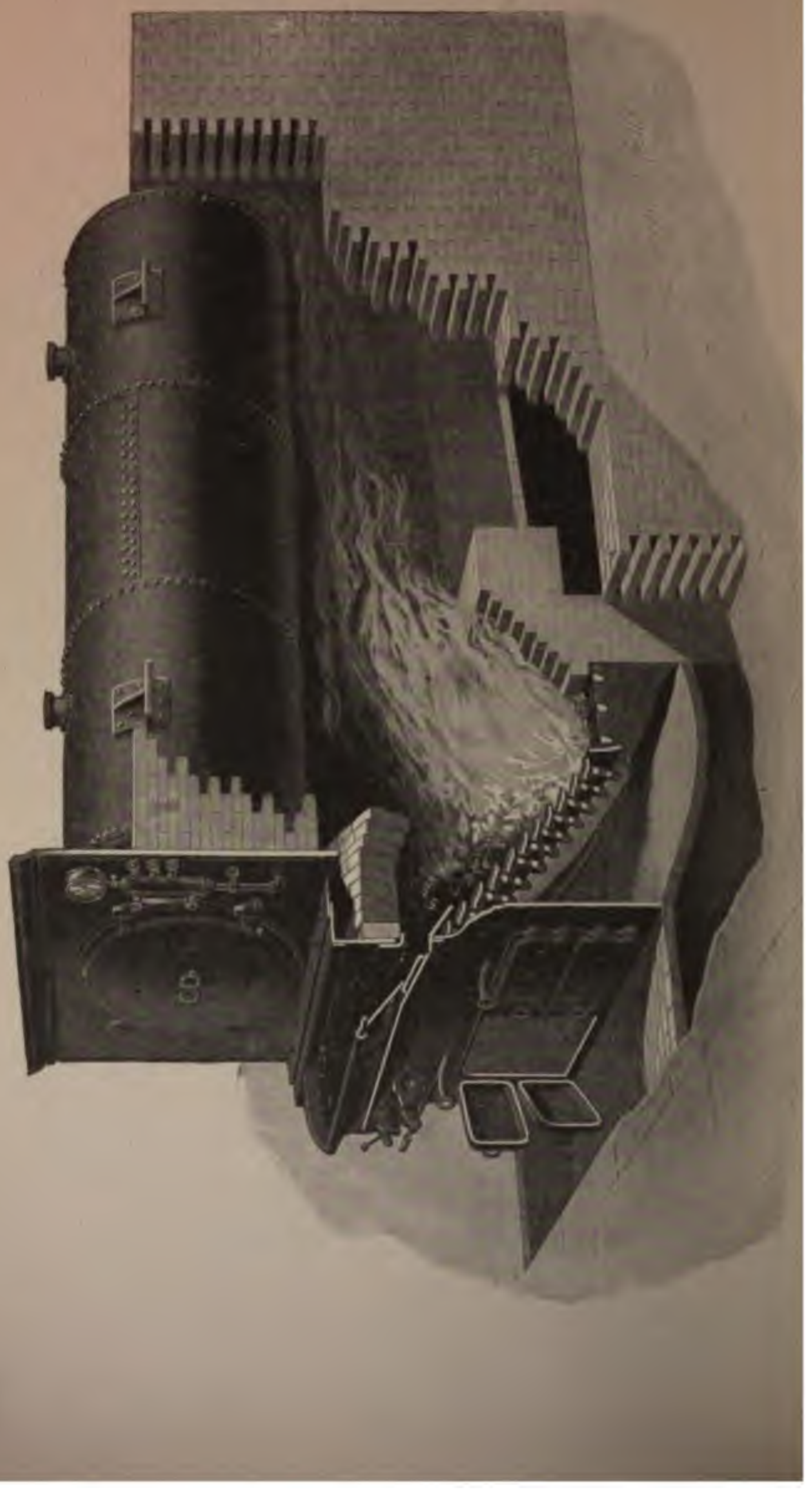


Brick Chimney of the Union Depot R'y Co., St. Louis, Mo.

As good natural earth should carry from 2000 to 4000 pounds per square foot, the base of the chimney should be large enough so that this pressure will not be exceeded.

The external shell is calculated for wind pressure and the weight of brick. This calculation for wind pressure involving higher mathematics will not be treated here. The lining is calculated for compression due to weight. The design, both of the chimney and its foundation, should be made by a competent engineer of experience, on account of disastrous results should a chimney fall.



TYPES OF BOILERS.

Generally speaking, a steam boiler is a closed metallic vessel in which steam is generated from water by the application of heat. As steam is under pressure it is evident that the vessel must be strong and tight.

To operate the boiler safely and economically there must be certain fittings and accessories—some of these are used in the care of the boiler, while others serve to increase the economy. Among the most important attachments and appurtenances may be mentioned the following:

A feed pump or injector, with valves, piping, etc., to supply water to the boiler.

Gage cocks and glass water gage to show the attendant the height of water or the water level, as it is called, in the boiler.

A pressure gage to show the pressure of steam in the boiler. The pressure is usually measured in pounds per square inch.

A safety valve to allow steam to escape from the boiler when the pressure exceeds a certain fixed amount. This attachment, being a safety device, should be automatic and reliable.

A blow-off pipe, with its valves, to blow out sediment from the boiler, reduce the amount of water in the boiler, or empty it.

A steam pipe, with its valves, to conduct the steam from the boiler to the place where it is to be used.

Manholes and handholes, with covers, for examination, repairs, and cleaning.

* **Fusible plugs** to give warning when the water level becomes too low, or melt and allow the water to escape.

* **High- and low-water alarms** to give warning when the water level is too high or too low.

* **A heater** to raise the temperature of the feed water as nearly as possible to that of the water in the boiler.

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*NOTE. Although the last three are desirable, they are not absolutely necessary, as a boiler can be successfully operated without them.

In addition to these there are other attachments such as:

Lugs or brackets for supporting the boiler.

Masonry for setting the boiler and keeping it in position, and in many cases to keep the hot gases in contact with the shell.

Furnace fittings, including grate bars, bearer bars, dampers, fire doors, ashpit doors, etc.

The chimney to carry away the waste gases and create draft.

Tools, such as shovels, slice bars, scrapers, tube brushes, etc.

DEFINITIONS.

The following definitions should be remembered in connection with the terms used in designating the various classes.

A fire-tube boiler is one having the heating surface composed largely of tubes which are surrounded with water, the hot gases passing through them.

A water-tube boiler is also composed of tubes, but in this case *water* flows through the tubes, while the hot gases pass around and among them.

In a sectional boiler the tubes and corresponding headers form comparatively small units. Each unit is complete in itself; that is, it is in communication with a steam and water drum but is independent of the other units.

A non-sectional boiler is one having all the tubes in communication with one another; in other words, all or nearly all the tubes are expanded into a common header or drum. The boiler is not made up of units.

A single-tube boiler is made up of plain tubes.

A double-tube boiler has a small tube inside of the regular tube and concentric with it.

A boiler is **externally-fired** when the furnace is separate from the shell; in such boilers the fire is usually placed in a brick furnace.

In the **internally-fired** boiler the grate is inside of a flue which is within the shell.

A fire-box boiler is one having the fire within a fire box which, although external to the shell, is rigidly connected to it. The fire box is usually made of steel plates instead of brick as in the case of the externally-fired boiler.

CLASSIFICATIONS.

The almost endless variety of boilers now in use is due largely to the many conditions under which they are used. Other reasons for the numerous forms are the great latitude in design and construction, and the competition among engineers, who have, during the last century, sought to produce, at moderate cost, steam generators that will be safe, durable, and economical.

The necessity for careful classification before discussing the details is apparent when one considers the similarities and differences. Much valuable time may be saved by selecting some make of boiler to represent a given class. Still further, the classification reduces the chances of overlooking interesting features.

CLASSIFICATION.

According to Use.

- **Stationary**
  - Early Forms.
  - Plain Cylindrical
  - Single Flue, Externally-fired
  - Flue Boilers
    - Cornish (single-flue)
    - Lancashire (two-flue)
    - Galloway
  - Multitubular
    - Externally-fired
    - Internally-fired (return-tube)
  - Fire-box Boilers
    - Horizontal
    - Vertical
  - Water-tube Boilers
    - Straight-tube
    - Curved-tube
    - Horizontal
    - Vertical
    - Sectional
    - Non-sectional
  - Mixed Types
  - Peculiar Forms
- **Marine**
  - Early Forms (box or rectangular)
  - Scotch or Drum
  - Return-tube
  - Through-tube
  - Water-tube
    - Curved-tube
    - Straight-tube
    - Sectional
    - Non-sectional
  - Launch Boilers
- **Locomotive**
  - Multitubular fire-box (common form)
  - Wooten Type
  - Corrugated Furnace
  - Peculiar Forms

Boilers may be classified in many ways. They may be divided into the following great classes: Fire-tube and water-tube, vertical and horizontal, stationary and non-stationary, or externally-fired and internally-fired. They may also be classified according to uses or according to forms of construction. For illustration, two classifications, of which the following seems better for this discussion, are given.

CLASSIFICATION.

According to Form of Construction.

Early Forms.

- **Flue**
  - Cornish (single-flue)
  - Lancashire (two-flue)
  - Galloway
  - Single Flue (externally-fired)
- **Fire-tube** (Multitubular)
  - Horizontal (common form)
  - Vertical
  - Return-tube
  - Through-tube
  - Fire-box
  - Peculiar Forms
- **Water-tube**
  - Horizontal
    - Straight-tube
      - Sectional
      - Non-sectional
    - Curved-tube
  - Vertical
    - Straight-tube
    - Curved-tube
  - Peculiar Forms

Mixed Types.

EARLY FORMS.

The earliest boilers of which we have reliable record were spherical. They were of cast iron and set in brickwork. It was customary to set this type of boiler with the fire underneath and construct flues in the brickwork to conduct the hot gases around the boiler just below the water level. The hot gases passed entirely around the boiler before escaping to the chimney.

The Haystack Boiler. The next form to be generally used was that invented by Newcomen in 1711. On account of its peculiar shape it was called the "Haystack" or "Balloon" boiler. It was of wrought iron and had a hemispherical top and arched bottom. The fire was placed underneath the arched portion; the hot gases surrounding the lower part of the boiler. An improved form of the Haystack boiler is shown in Fig. 1. Smeaton placed the fire inside the shell and arranged internal flues for conducting the hot gases to the chimney. This arrangement increases the heating surface and consequently the economy of the boiler.

The Wagon Boiler. To still further increase the heating surface, James Watt introduced his "Wagon" boiler. This form is shown in Fig. 2. The top was cylindrical and the sides curved inward. The curved plates assisted in the formation of flues on either side. The hot gases passed from the grate, underneath the boiler to the rear, through the left-hand flue to the front, then through the right-hand flue to the rear and thence to the chimney. This was called the *wheel draft* because the gases passed entirely around the boiler. In the large sizes a flue was placed in the boiler. The products of combustion returned through this flue to the front after passing under the boiler to the rear, as in the small sizes. On issuing from the flue at the front, the gases divided and passed to the chimney at the rear by means of the flues in the brickwork. This form of draft was called the *split draft*.

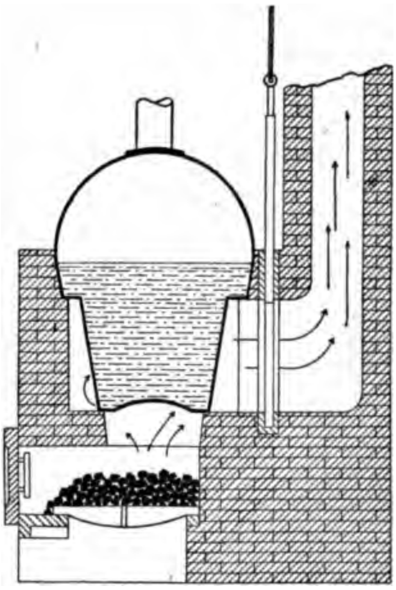


Fig. 1.

Watt used a column of water in the vertical feed pipe as a pressure gage; the rise and fall of this column also controlled the damper. The feed was regulated by a float.

MODERN BOILERS.

Although such boilers as the Haystack, Wagon, and others were fairly satisfactory in the period in which they were invented, they could not stand the higher pressures that soon became common.

About the beginning of the nineteenth century the cylindrical boiler was introduced. The earliest forms were the plain cylindrical boiler and the "Egg-end" boiler. The difference was in the form of the ends — those of the former were flat and of cast iron, while the ends of the latter were hemispherical and made of wrought iron. The egg-end boiler required no staying or bracing because its form is, with the exception of a sphere, the strongest to resist internal pressure.

The Cylindrical Boiler consisted of a shell of wrought-iron boiler plate and ends of the same material or of cast iron. It was set in brickwork as shown in Fig. 3. The boiler was about two-thirds filled with water, the remaining third forming the steam space. To collect and store the steam as it rose from the water a steam dome was added. The steam pipe was attached to the dome to which the safety valve also was connected. The hot gases from the fire passed under the boiler to the rear and then to the chimney.

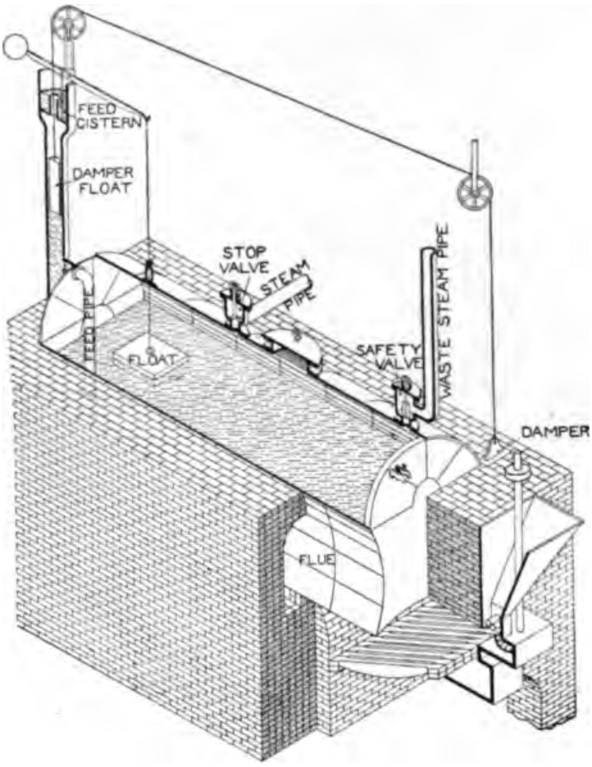


Fig. 2.

The heating surface of this type is small with a given diameter unless the boiler is made very long. As all sediment collects in the bottom, where the heat is most intense, the plates are liable to burn. Since sediment and scale are poor conductors of heat, the heat remains in the plates and overheats them instead of flowing to the water.

The disadvantages (the small heating surface and the collection of sediment) do not seem so serious when one considers the simplicity of construction, strength, durability, and ease of repairing and cleaning.

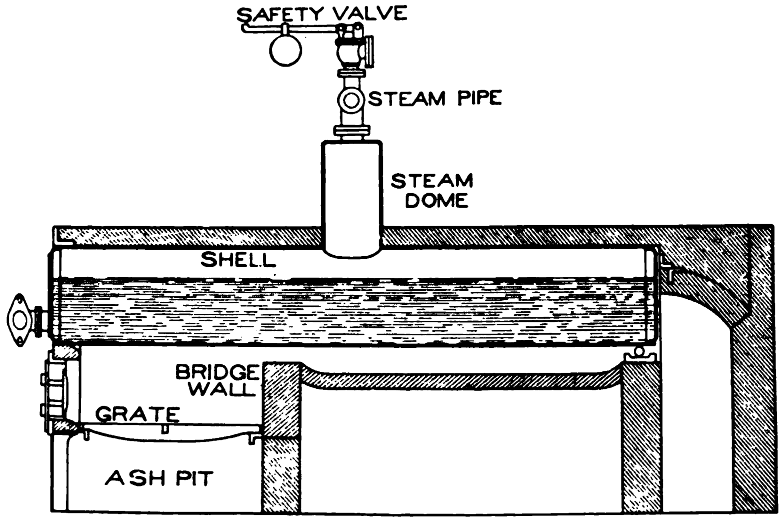


Fig. 3.

The plain cylindrical boiler was adapted for mining districts, iron works and other places where fuel is abundant and skilled boiler makers are not readily found. This boiler was made very long to get the required heating surface, the length sometimes exceeding fifty feet.

FLUE BOILERS.

In order to get the necessary heating surface in the cylindrical boiler without making it excessively long, it was made with an internal flue through which the hot gases passed to the chimney. This flue was quite large and extended from end to end. In the

United States, Oliver Evans used this type in 1800. In England, it led to the internally-fired flue boilers which were so extensively used.

THE CORNISH BOILER.

Horizontal—Single-Flue—Internally-Fired.

When it was found that about 25 per cent of the total heat of combustion was lost by radiation from the furnace, a Cornish engineer named Trevithick, conceived the idea of placing the fire inside the large internal flue. He introduced this type which is known as the Cornish boiler.

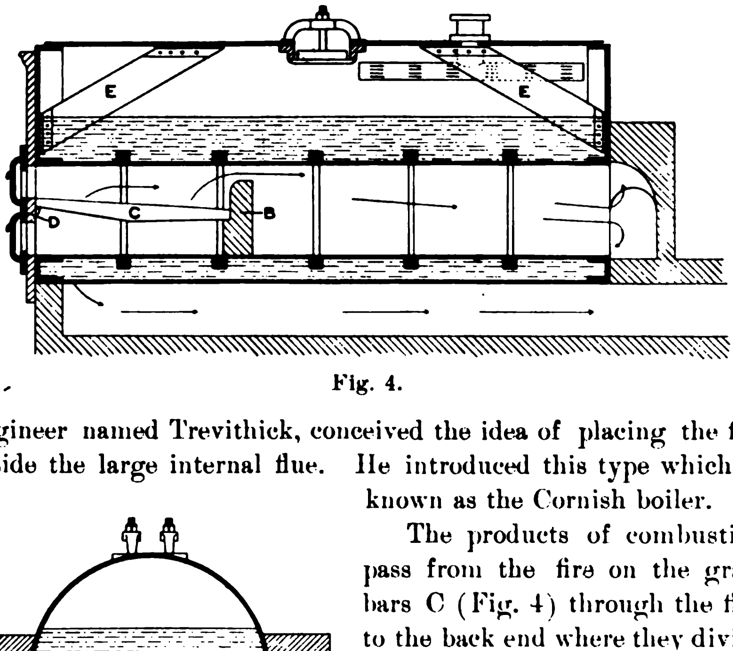


Fig. 4.

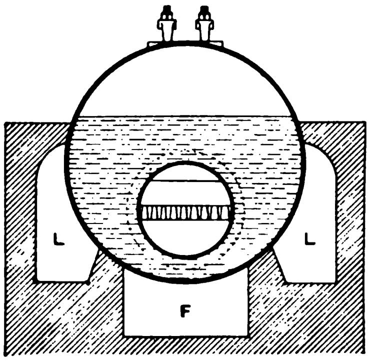


Fig. 4*a*.

The products of combustion pass from the fire on the grate bars C (Fig. 4) through the flue to the back end where they divide and return to the front end by means of the lateral flues L in the brickwork. See Fig. 4*a*. At the front the hot gases pass downward, and uniting pass through the flue F in contact with the bottom of the boiler. On leaving the boiler they go to the chimney. This arrangement of flues reduces the temperature of the gases before they come in contact with the bottom of the boiler where sediment collects. The grate bars rest on the dead plate D at one end and on the bridge B at the other; if made in two lengths (as is often the case) they are supported at the center by a cross bearer. The bridge is built of fire brick and the external flues are lined with fire brick. The heads are stayed to the shell by gusset stays E E.

The large internal flue is the hottest portion of the boiler because it contains the fire. For this reason the flue has greater linear expansion than the shell and, if the flue is a plain cylinder, the increase in length causes the ends to bulge. When the boiler is cold, the flue returns to its normal length. This lengthening and shortening will soon loosen the flue at the ends. To overcome this, the flue is sometimes made up of several short rings flanged at the ends and joined by being riveted to a plain ring. This construction is shown in section in Fig. 4. Another method is shown in section in Fig. 5. The plain ring is riveted to the curved ring; this ring takes up the expansion, increases the heating surface, and strengthens the flue against external pressure. The same results may be obtained by the use of the corrugated flue, one form of which is shown in Fig. 6. The corrugated flue has many advantages over the devices shown in Figs. 4 and 5; it is frequently used in marine boilers.

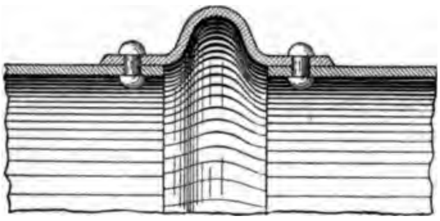


Fig 5.

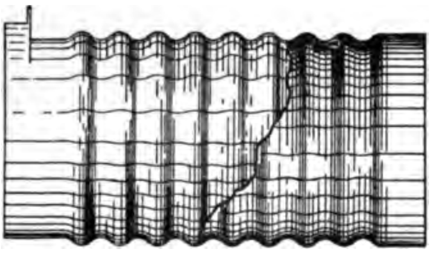


Fig. 6.

LANCASHIRE BOILER.

Horizontal Two-Flue--Internally-Fired.

It can be proved, both by experiment and calculation, that with a given thickness large cylinders cannot stand as much external pressure as small ones. For this reason and on account of the short distance a fireman can throw coal accurately, the Cornish boiler is suitable for small powers only. If it is made too large, the flue is liable to collapse, but if, on the other hand, the flue is of too small a diameter, the grate will be insufficient. If this form of boiler is to be used in large size it is modified by using two flues instead of one. This boiler is called the Lancashire boiler. It is like the Cornish type except that it has two flues and, of course, two furnaces.

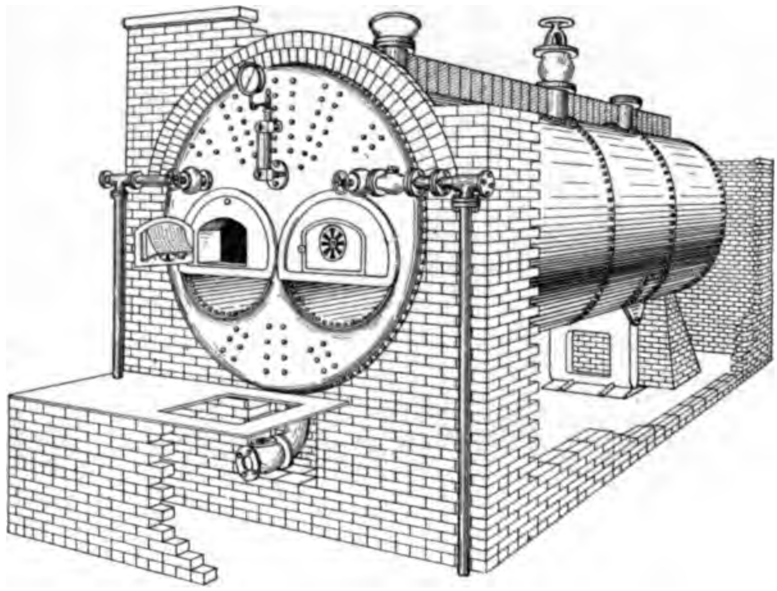


Fig. 7.

The flues are sometimes continued separately to the end. If they merge into one large flue, which forms the combustion chamber, it is called the "Breeches-flued" or duplex furnace boiler. These furnaces are fired alternately; the unburned gases set free from the freshly-fired coal are burned on meeting the hot gases from the incandescent coal of the other furnace. This arrangement prevents the escape of the unburned hydrocarbons.

The disadvantage of the Lancashire boiler is the difficulty in finding room for the two flues without greatly increasing the diameter of the boiler. Also, the small furnace is unfavorable to complete combustion as the space for the uniting and burning of the hydrocarbons is restricted. The combustion chamber of the breeches-flued boiler provides the necessary space, but the construction at the junction of the two flues is weak and has been the cause of many explosions.

GALLOWAY BOILER.

Horizontal—Two-Flue—Internally-Fired—Galloway Tubes.

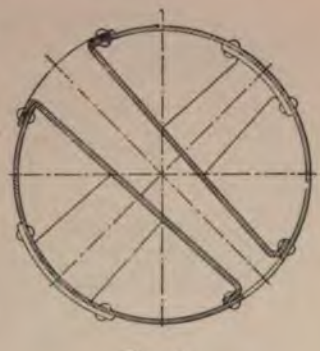


Fig. 8.

Another boiler of the same general form is the Galloway, shown in Fig. 7. This boiler differs from the Lancashire in that short tubes are added to the flues. In the Galloway boiler having two distinct flues, the tubes were placed as shown in Fig. 8.

In the later form of Galloway boiler, the two flues merge into one large flue of the shape shown in Fig. 9. This flue has corrugated sides and the conical tubes are staggered, thus insuring a thorough breaking up of the currents of hot gases. The tubes are made conical to facilitate removal for repairs. The shape of the tube also permits the water to expand on being heated, and the par-

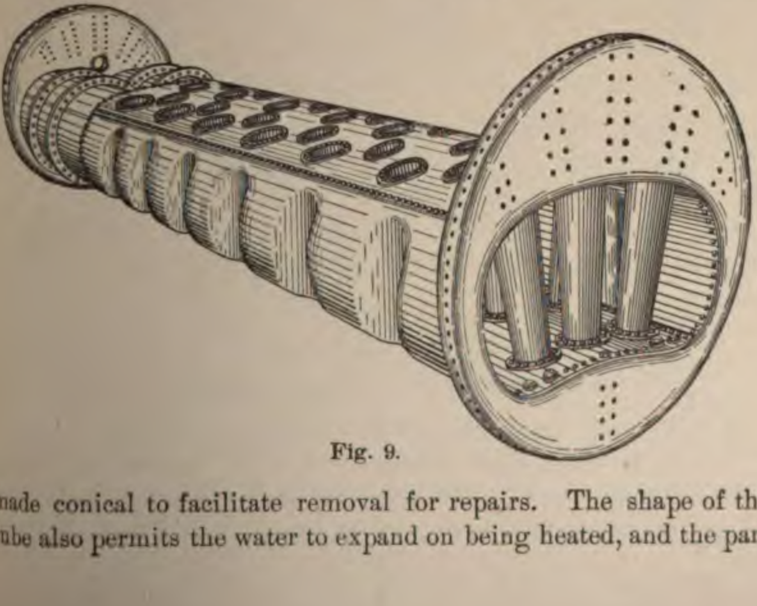


Fig. 9.

ticles rise vertically without disturbing the water on the heating surfaces above. The conical tubes are generally riveted rather than welded because the removal of a tube that is welded leaves a large hole in the flue.

FIRE-TUBE BOILERS.

SINGLE-FLUE BOILER.

Horizontal—Single Fire Tube—Externally-Fired.

In the Cornish, Lancashire, and Galloway boiler the large internal flue served as a fire box. There was, however, a flue boiler having the fire external to the shell. The boiler shown in Fig. 10 resembles the plain cylindrical boiler both in appearance and setting, but it has one or more large flues extending from end to end. This flue increases the heating surface to such an extent that the boiler can be considerably shorter than the plain cylindrical.

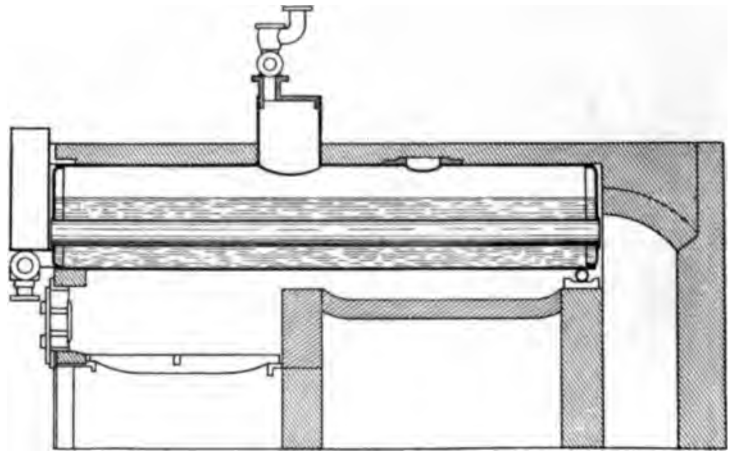


Fig. 10.

MULTITUBULAR BOILER.

Horizontal Many Small Fire Tubes—Externally-Fired.

When engineers found that the internal flue was such an advantage (that is, it increased the heating surface), they soon added more tubes; as the number increased, the size diminished until they became of the size used at present. This is in brief the development of the multitubular boiler. This type of boiler has for many years been commonly used for stationary work and although other types possess advantages for certain conditions, it is still considered economical, reliable, easily handled, and safe if constructed of good material and operated with care and intelligence.

Figs. 11 to 14 are selected to illustrate this boiler. The boiler without the brick setting is shown in Fig. 11. It consists of a steel cylindrical shell and numerous small tubes extending from end to end. These tubes are 3 or 4 inches in diameter and are fastened to the two ends (called tube sheets) by expanding the tubes against the sheet and beading them over on the outside. The shell is made of steel plates $\frac{1}{4}$ to $\frac{3}{4}$-inch in thickness. At the front, the shell plates extend beyond the tube sheet and are cut away to allow the waste gases to enter the uptake. About one-third the volume of the boiler is occupied by the steam; the other two-thirds is filled with water and tubes. The water line is a little (from 4 to 8 inches) above the top row of tubes.

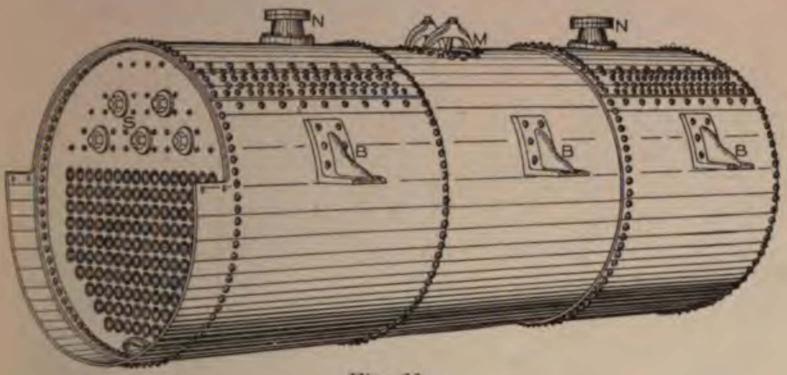


Fig. 11.

The flat ends are prevented from bulging by stays which may be of the form shown in Fig. 12 or they may be diagonal stays. The through stays are fastened to the tube plates by means of nuts and washers as shown at S in Fig. 11, and also in Fig. 12. Below the water level, the end plate is stayed by the tubes. This type of boiler may be supported by brackets B riveted to the shell or by means of beams and columns, as shown in Fig. 14. The front bracket is often fixed in the side wall, but the rear bracket should be placed on rollers so that it can move on an iron plate. This

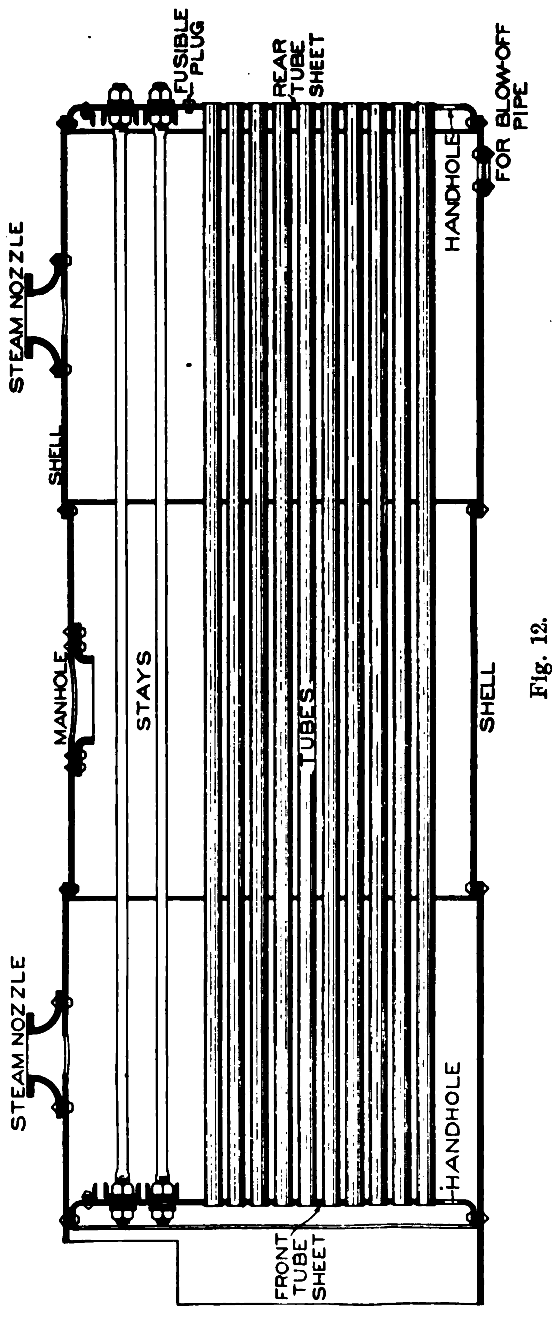

STEAM NOZZLE
SHELL
MANHOLE
STEAM NOZZLE
FUSIBLE PLUG
STAYS
REAR TUBE SHEET
TUBES
FRONT TUBE SHEET
HANDHOLE
HANDHOLE
SHELL
FOR BLOW-OFF PIPE

Fig. 12.

will prevent the straining of the plates from expansion and contraction. A small space must be left between the rear tube sheet and the brick wall to allow for expansion.

The boiler shown in Fig. 11 has two steam nozzles N. If the boiler has a dome (D Fig. 13) the steam nozzle is at or near the top of the dome The feed pipe may enter either at the front or at the rear. It frequently terminates in a perforated pipe below the water line. The blow-off pipe is at the rear of the boiler as shown in Fig. 13 A valve, called the blow-off valve, regulates the flow and may be opened, when there is low pressure in the boiler, to blow out sediment and detached scale. The boiler is usually set with a slight inclination toward the rear so that mud and detached scale may collect near the blow-off pipe.

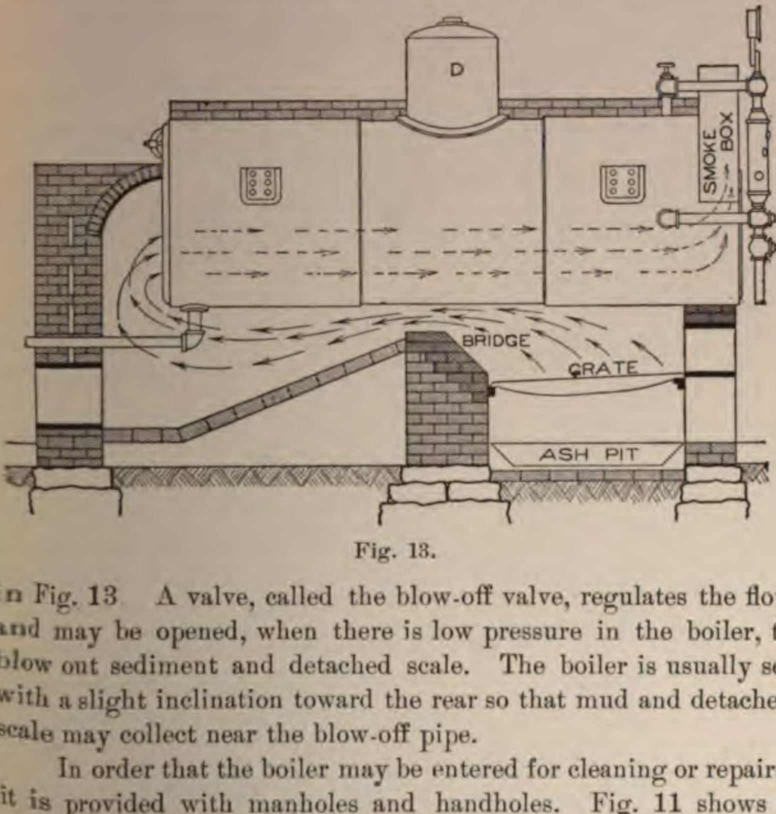


Fig. 13.

In order that the boiler may be entered for cleaning or repairs, it is provided with manholes and handholes. Fig. 11 shows a manhole M at the top near the middle and a handhole near the bottom of the front tube sheet. Handholes may be put in wherever desired, but manholes can be located only where the arrangement of stays and tubes will permit the entrance of a man. Manholes and handholes are elliptical; the former being about 11 inches by 15 inches in size; while the latter are about 4 inches by 6 inches.

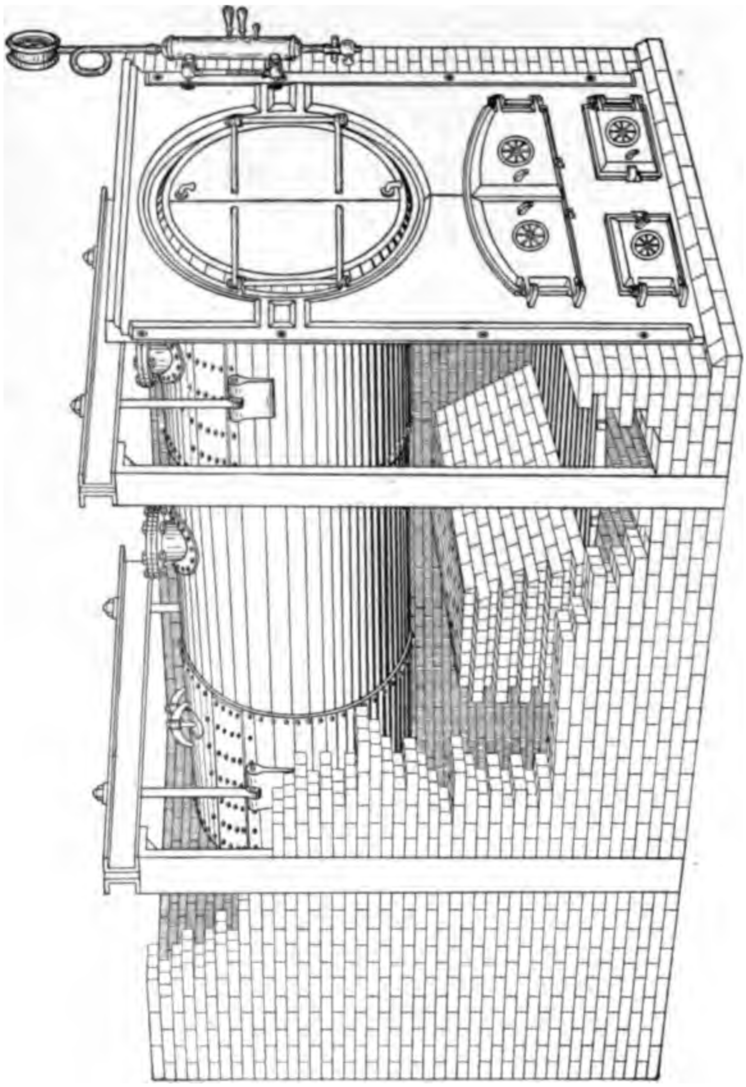


Fig. 14.

The heating surface is the surface in contact with the hot gases. In this type, the heating surface is made up of about half the shell, the tubes, and about two-thirds of the rear tube sheet. In general, all the heating surface is below the water line.

The complete multitubular boiler is shown in its brick setting in Fig. 14, and a longitudinal section of the setting in Fig. 13. The brick setting consists of brick laid in cement or mortar. The bridge and the portions of the furnace exposed to the fire are lined with fire brick. The bridge is built at the rear of the grate and forms a support for the grate bars; it also directs the flames upward. The arrows show the direction of the flow of hot gases. The furnace is formed by the bridge, the side walls, and the lower part of the boiler front. The boiler front is usually of cast iron with the lower part lined with fire brick. The front has doors which lead to the furnace, ashpit, and smoke box. The space below the grate is called the ashpit, and through its doors ashes are removed and a large portion of the air for combustion enters. Both the fire doors and ashpit doors have draft plates, or grids, to regulate the supply of air. The doors to the smoke box give access to the tubes for cleaning and repairs.

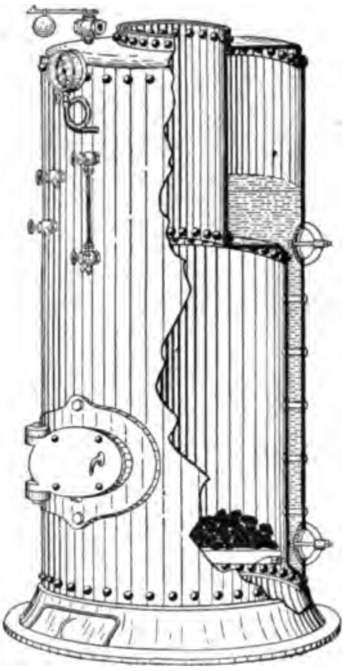


Fig. 15.

UPRIGHT BOILERS.

Vertical—Many Small Fire Tubes—Fire Box.

Upright boilers are used when floor space is valuable and there is sufficient height. In small sizes, they are used for hoisting engines, pile driving, for supplying steam for pumps, and similar work; in large sizes when it is necessary to have a powerful battery in a small space. In general they are not as economical as the horizontal multitubular boiler unless they are carefully designed and of considerable height. If the tubes are short, the hot gases escape before they give up much of their heat.

One of the simplest forms of upright boiler is shown in Fig. 15. It has a cylindrical shell with a large fire box at its lower end. This fire box is formed by the inner cylinder which is fastened to the outer shell by short screw stay bolts as shown. A flanged ring connects the fire box with a large flue which conducts the hot gases away. The necessary handholes, gages, safety valves, etc., are provided. This form is not economical but is used on account of the little attention required.

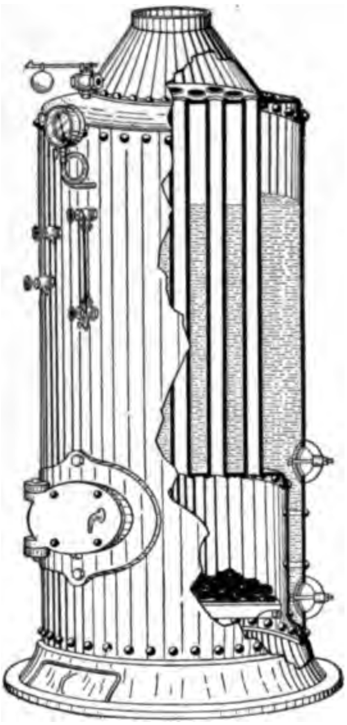


Fig. 16.

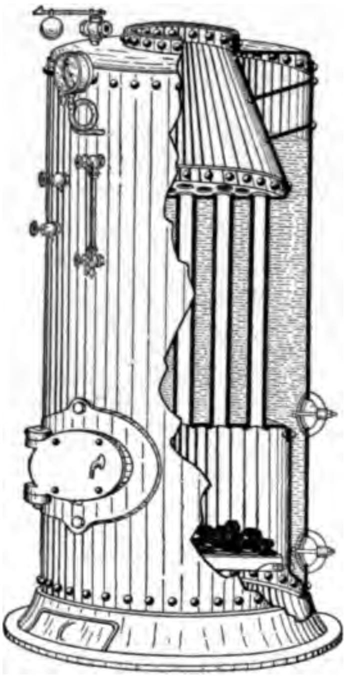


Fig. 17.

More economical forms of the small upright boiler are illustrated in Fig. 16 and 17. The boiler shown in Fig. 16 is a common form; externally it is like the boiler represented by Fig. 15, but within, it has a somewhat different construction. It resembles a multitubular boiler placed on end. The fire box is made of an inner cylinder stayed to the outer. The top of the fire box, called the lower tube sheet, is connected to the upper head by tubes, through which the hot gases pass to the smoke pipe. It will be readily seen from Fig. 16, that the upper ends of the tubes are surrounded with steam while the lower portions are covered with water. As steam is a poor conductor of heat, the ends of these tubes are liable to injury from overheating.

In the class of boiler shown in Fig. 17 the upper ends of the tubes are below the water level, thus avoiding the weakness described in connection with Fig. 16. The upper tube sheet is submerged and is flanged and riveted to the frustum of the cone which forms the smoke box. The chief defect in this boiler is that the lower part of the cone is often placed too near the shell; this is done to admit more tubes. This construction restricts the space so much that there is not sufficient room for the steam to rise as it is formed on the tubes. The cone, which is subjected to external steam pressure, is likely to be weak and is usually carefully stayed.

These small upright boilers require no brick setting, as the fire box is within the boiler and the cast-iron foundation forms the ashpit.

MANNING BOILER.

Vertical—Many Small Fire Tubes—Fire Box.

The Manning boiler is illustrated in Fig. 18. In order to get a large heating surface, it is made 20 to 30 feet high. It is, in general, similar to the upright boiler shown in Fig. 16. At the lower portion, the shell is of greater diameter than at the top in order to provide a large grate area. The inner fire box is stayed to the shell by screw stay bolts. As the fire box is surrounded by water and there are many long tubes there is a large heating surface. The tubes are arranged in concentric circles with a space for circulation in the middle.

The external fire box is joined to the shell by a double flanged ring as shown in Fig. 19; or, by the cone-shaped section as illustrated in Fig. 20. The top edge of the internal fire box is riveted to the lower tube sheet which is flanged. The bottom of the inner fire box is connected to the outer shell by a welded ring (shown

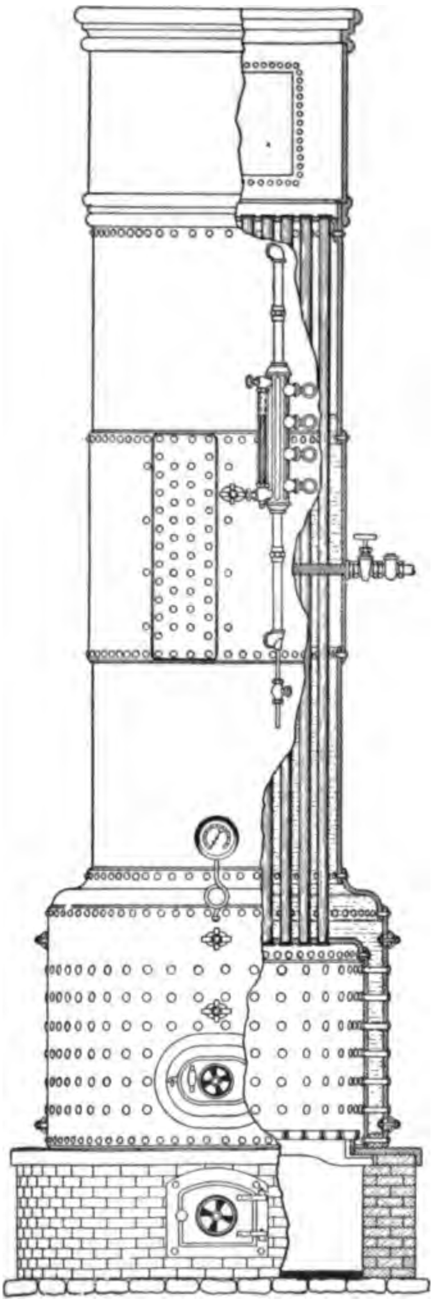


Fig. 18.

in section in Figs. 19 and 20) called the foundation ring. The water space between the inner and outer fire box plates, called the water leg, should be large.

This boiler is cleaned by means of handholes. They are placed in the shell plates near the lower tube sheet, in the external fire box just over the furnace door, and at the bottom near the foundation ring. As there are no manholes for cleaning, the boiler is suited to good feed water only.

The feed pipe enters the shell at the side near the middle of the water space, and extends across the boiler; it is perforated to distribute the water.

The heating surface consists of the inside of the fire box and the tubes up to the water level, and the tube sheet. That part of the tubes *above* the water line is the superheating surface; that is, the heat from the gases passes through the metal of the tubes to the steam, thus raising its temperature without raising its pressure. Steam heated under these conditions is called superheated steam. In small vertical boilers this superheating surface is not desirable because the work of the small boiler does not require superheated steam and the tubes are likely to be burned by the intense heat. With the long tubes of the Manning, the gases are not as hot when they reach the top, and as this boiler is built in large powers (200 horse-power being common) the engines supplied are built for economy and require dry if not superheated steam.

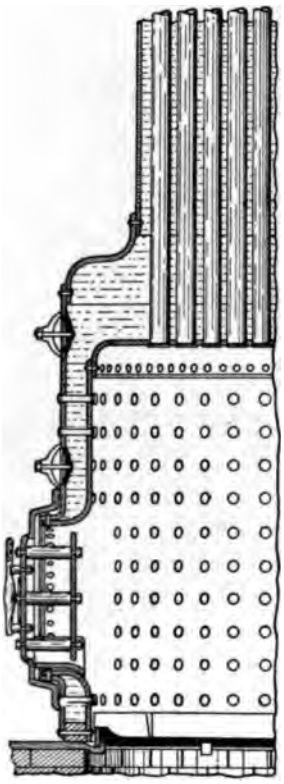


Fig. 19.

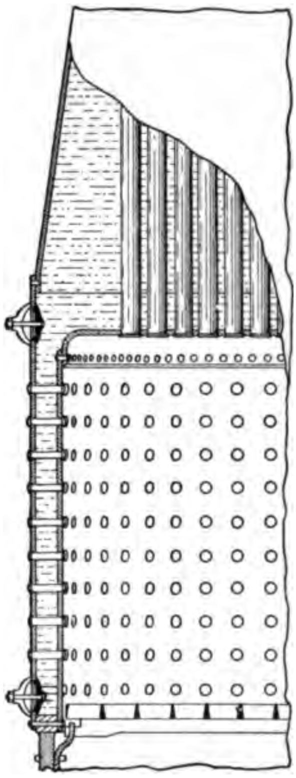


Fig. 20.

RETURN-TUBE BOILERS.

Horizontal---Many Small Fire Tubes—Internally-Fired.

The boilers hitherto described are used mainly for stationary work, the exceptions being so few that they need not be even mentioned. Let us now discuss another modification of the fire-tube boiler—one that has been and is now extensively used in marine work. The parts of the return-tube boiler are essentially the same as those of flue boilers (Cornish and Lancashire) and the multitubular boiler. They are, however, arranged differently in order to be used on board ship.

The earliest forms of marine boilers, working with pressures of 15 to 30 pounds per square inch, were square or box-shaped. They were economical and of convenient form for ships. When higher steam pressures became necessary, the flat surfaces required so much staying that they were abandoned and the cylindrical type introduced, as this form is the best of the practical shapes to resist internal pressure. The cylindrical form may not be as conveniently stowed aboard ship, but it will stand much higher pressures. The cylindrical marine boiler is frequently built for 170 pounds per square inch.

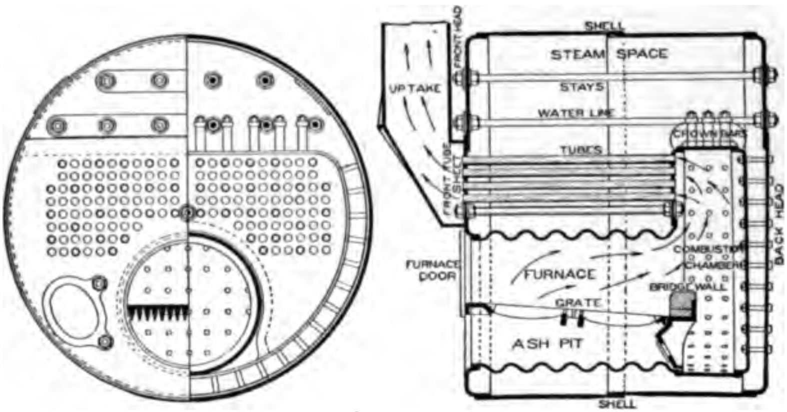


Fig. 21.

The single-ended, return-tube boiler, shown in Fig. 21, combines the internal furnace flue of the Cornish type and the numerous small fire tubes of the multitubular. The cylindrical shell is made up of plates riveted together and to the flat ends of the boiler, which are flanged to fit the shell.

The furnace is cylindrical, three to four feet in diameter and about seven feet in length. The front end of the furnace flue is riveted to the front end plate, which is flanged for the purpose. The back end is riveted to the combustion chamber plates. Formerly, the flue was a plain cylinder, but as a plain cylinder, unless of small diameter, cannot stand much external pressure, it soon became necessary to strengthen it. This was done by means of the curved ring shown in Fig. 5 and other methods; but at present the corrugated flue is used, one form being shown in Fig. 6.

The grate is placed at about the center of the height of the furnace flue; the space above this grate is occupied by the fire and hot gases, below it is the ashpit. As will be seen from the arrows in Fig 21, the hot gases fill the space above the fire, the combustion chamber, the tubes and the uptake.

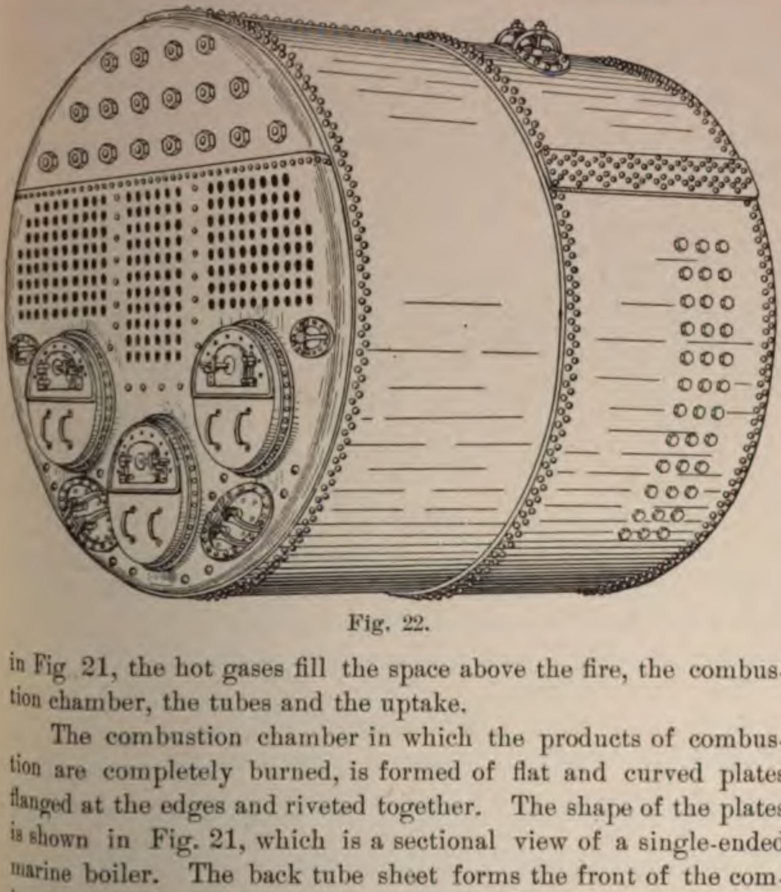


Fig. 22.

The combustion chamber in which the products of combustion are completely burned, is formed of flat and curved plates flanged at the edges and riveted together. The shape of the plates is shown in Fig. 21, which is a sectional view of a single-ended marine boiler. The back tube sheet forms the front of the combustion chamber. The space around the tubes, furnace flue, and combustion chamber is filled with water, the water level being six to eight inches above the top row of tubes. The space above the water level is called the steam space.

As the return-tube boiler has several flat surfaces, this type requires careful staying. The flat ends above the water level are prevented from bulging by long stay rods which are similar to those in the multitubular type. Below the water level, the furnace flue and the tubes aid in holding the flat plates together. In addition, a few of the tubes (shown by the heavier circles in Fig. 21) are made thicker so that a thread may be cut on the ends which are screwed into the tube sheets and held by thin nuts. The combustion chamber plates are stayed to the rear end plate and the shell by short screw stay bolts. The flat top of the combustion chamber is supported by girders or crown bars.

Number of Furnaces. The boiler shown in Fig. 21 has only one furnace, but return-tube boilers frequently have two, three, or four furnaces.

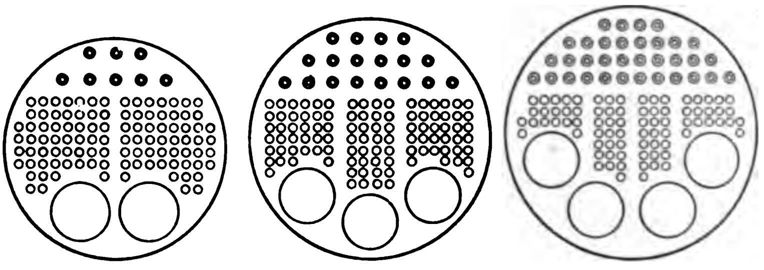


Fig. 23.

Fig. 22 shows a boiler with three furnaces. Large furnaces are more efficient than small ones because the grate area increases directly as the diameter, while the air space above the grate increases as the square of the diameter. The greater space aids combustion. The length of the grate bars is nearly constant for all sizes of flue because it is limited by the distance a fireman can throw coal. Furnace flues are usually from 36 to 54 inches in diameter. As the size of furnaces is fixed, the number depends upon the size of the boiler, for a large boiler must have a large grate area which can be obtained only by using several furnaces. The various arrangements are shown diagrammatically in Fig. 23.

A single-furnace boiler has but one combustion chamber. A two-furnace boiler may have a combustion chamber for each furnace or it may have a common combustion chamber. If there is but one boiler on board, it is better to have two combustion chambers, so that in case a tube bursts, the boiler will not be disabled. If, however, there are several boilers, it is better to have a common combustion chamber for the two furnaces, because the alternate stoking keeps up a more nearly constant pressure of steam and there is less smoke. Three-furnace boilers usually have three combustion chambers, while four-furnace boilers have two. In case four furnaces are used with three combustion chambers, the two center furnaces lead to a common combustion chamber and each outside furnace has one.

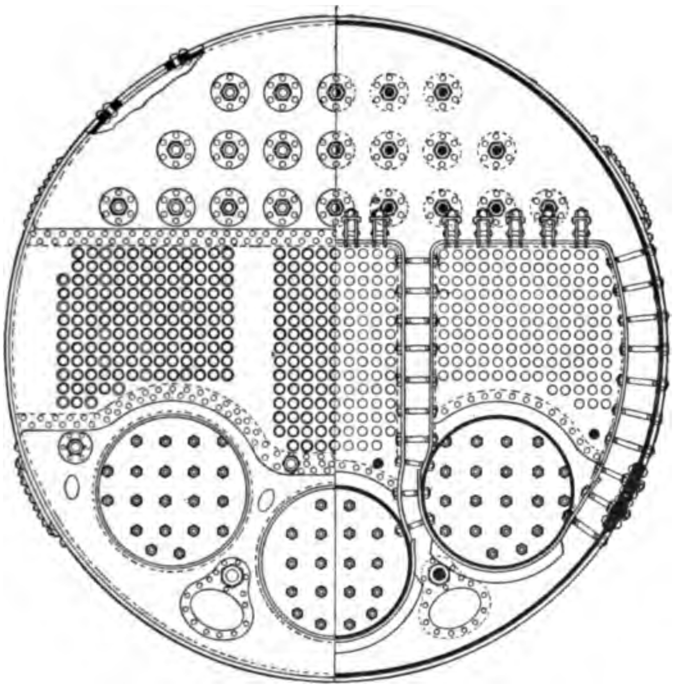


Fig. 24.

Double-ended Boilers. This form of marine return-tube boiler is practically the same as two single-ended boilers placed back to back, but with the rear plates removed. The weight of the rear plates is saved and there is less loss from radiation. This makes the double-ended boiler lighter and cheaper in proportion to the heating surface. Double-ended boilers are often made 16 feet in diameter and 18 feet long.

There are two distinct classes of double-ended return-tu boiler—those having all the furnaces open into one combusti chamber and those having several combustion chambers. T boiler having but one combustion chamber has the disadvanta that if one fire is being cleaned the whole boiler may be cooled

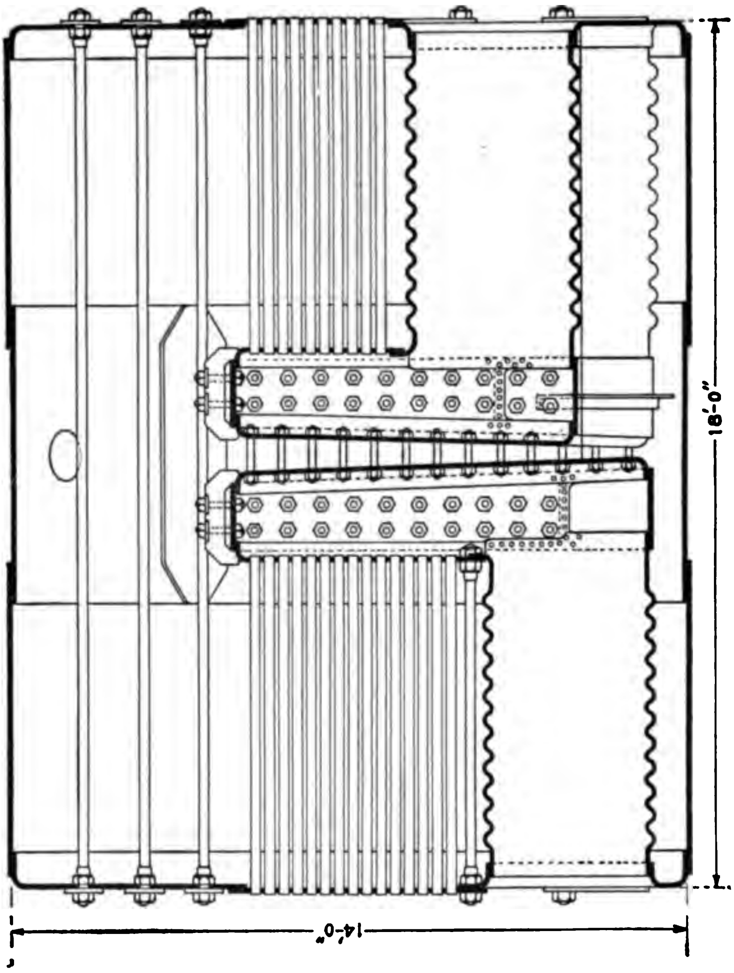


Fig. 24.

the inrush of cold air. It is better to have a combustion chamb for each furnace or at least have a combustion chamber for the fu naces of each end. The usual method of dividing up the combu tion chambers is by water spaces as shown in Fig. 24, which is t section of a boiler having a combustion chamber for each furna

Internal Furnace Return-Tube Boiler. Although the return-tube boiler is commonly used in marine work, this type, with some changes in detail, is used in plants ashore. Fig. 25 shows the construction and arrangement of parts. The flue is larger in proportion to the diameter than is the case with the marine form; the combustion chamber is partly external to the shell, that is, the rear tube sheet is also the rear end plate. This arrangement does away with the necessity of staying the flat plates of the combustion chamber.

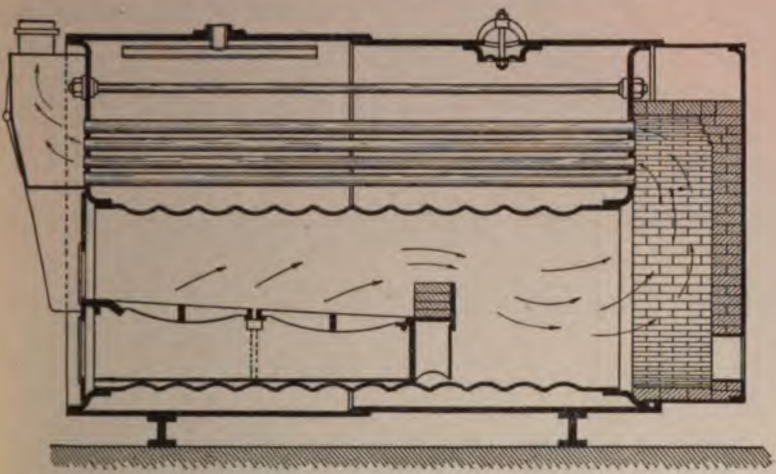


Fig. 25.

Another form of internal furnace, return-tube boiler is shown in Fig. 26. This boiler usually has two flues extending from the front to the back head. The grate is placed in the corrugated portion while conical water tubes support the flue back of a bridge wall. The large furnaces and the space around the conical tubes provide a combustion chamber of ample size.

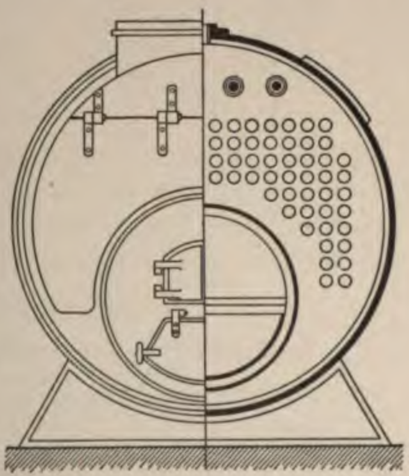


Fig. 25.

The arrows show the direction of the hot gases. After lea ing the internal flue they enter the return tubes which are bel the furnace; before leaving the boiler, they pass underneath t shell. By this arrangement the hottest gases are near the wa line and the cooler gases in contact with the cold water, thus th is the greatest difference in temperature at all times. At ea change in the direction of the hot gases, there is an opportun for dirt and ash to fall by gravity so that the tubes may rem clean and efficient.

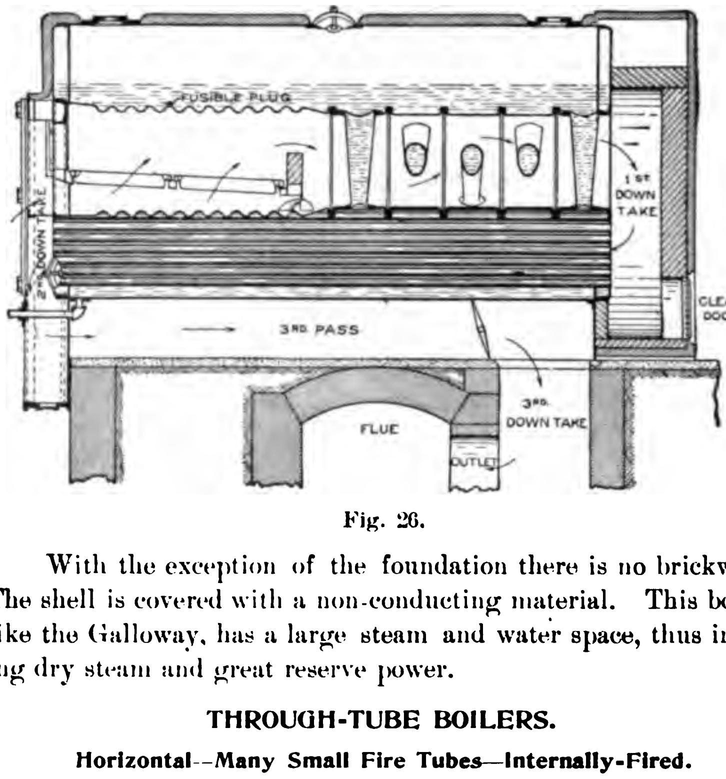


Fig. 26.

With the exception of the foundation there is no brickwo The shell is covered with a non-conducting material. This boil like the Galloway, has a large steam and water space, thus ins ing dry steam and great reserve power.

THROUGH-TUBE BOILERS.

Horizontal--Many Small Fire Tubes—Internally-Fired.

Vessels of slight draft require a boiler of small diamet This is especially true of gunboats as it is desirable to have t boilers below the water line. As there is not room for the retur tube boiler, the through-tube, shown in Fig. 27, is sometim used. This boiler is made up of the same parts as the retu tube, the chief difference being that of arrangement. The re plate of the combustion chamber forms one tube sheet and the end plate forms the other. The top of the combustion chamber is stayed to the shell by sling stays which are bars having forked ends fastened to the shell and to the combustion chamber.

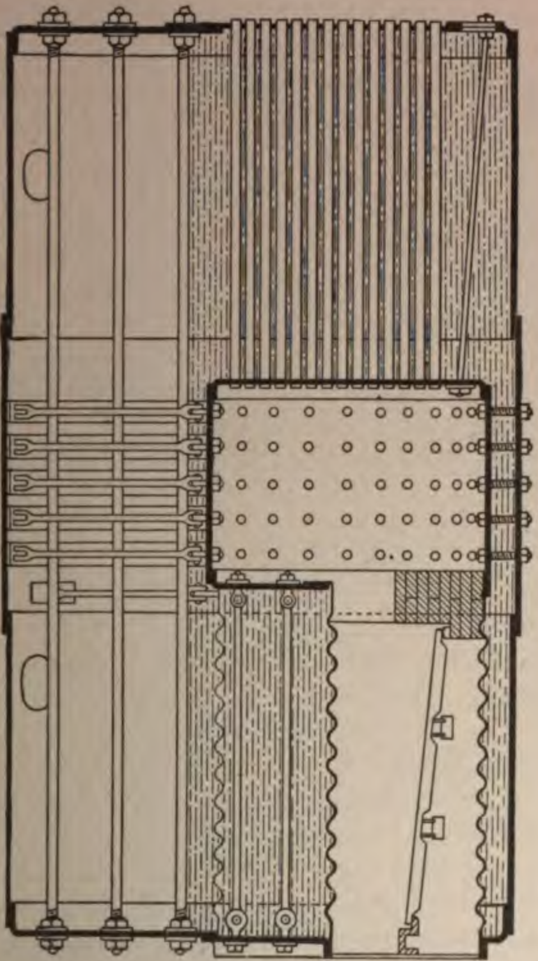


Fig. 27.

The fire is in a flue, or flues, which leads to the combustion chamber. The hot gases pass from the combustion chamber through the tubes to the uptake at the back end. The chief objection to this form is its length, for the heating surface is small unless the boiler is made very long.

FIRE-BOX BOILERS.

LOCOMOTIVE TYPE.

Horizontal—Many Small Fire Tubes—Externally-Fired.

Although vertical fire-tube boilers may be classed as fir boilers, yet the name fire-box boiler is usually applied to the motive type whether used with a locomotive or as a stationary b

The usual form of horizontal fire-box boiler consists of indrical shell, or barrel, partly filled with tubes, and a rectan

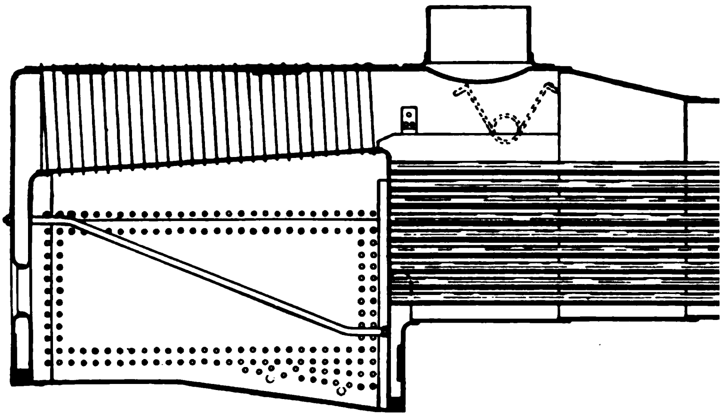


Fig. 28.

fire box. The shell is prolonged beyond the rear tube she form a smoke box. The front ends of the tubes open into the box, while the rear ends open into the smoke box. The hot from the fire pass through the tubes to the smoke box and thence to the stack or uptake. For locomotive work, there large number of small tubes (usually 2-inch), but for stati work the tubes are larger and less numerous. The reason fo difference is that in the locomotive boiler a greater heating su is necessary, and to obtain sufficient draft to burn the large a of coal for this heating surface, the exhaust steam is turned the smoke box. The blast of steam carries the heated gas the stack and a fresh supply of air passes through the grate.

The cylindrical shell is joined to the fire box by riveting flanged ring or to a cone-shaped portion as in the vertical b The fire box has a rectangular cross-section and usually a fla

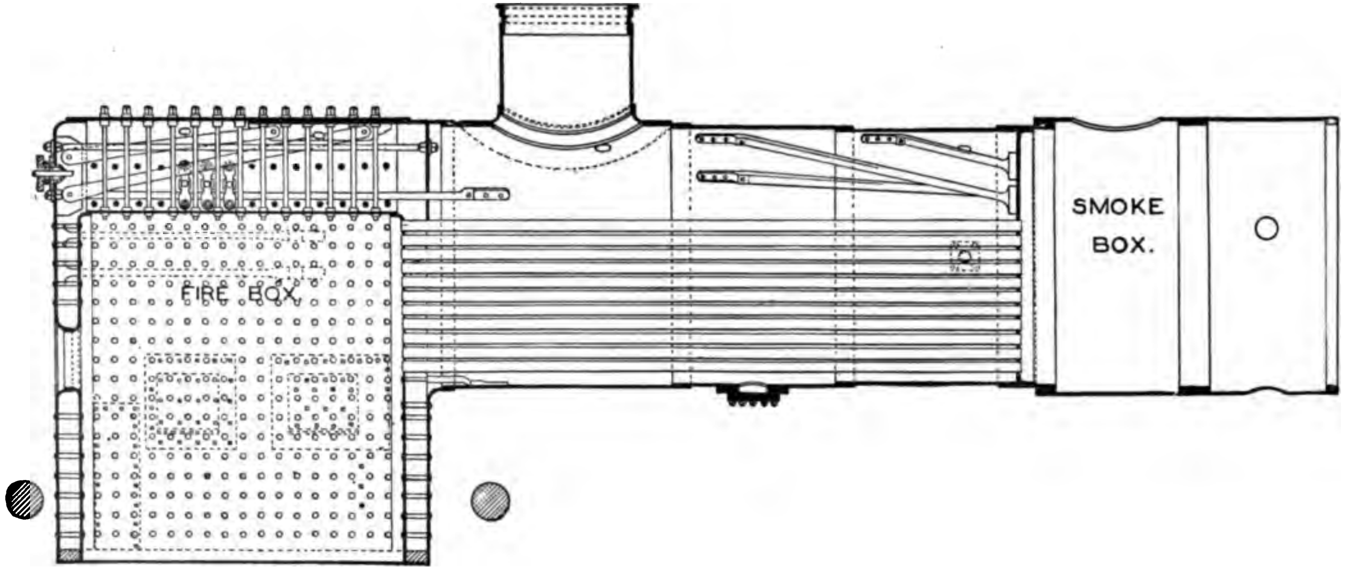


Fig. 29.

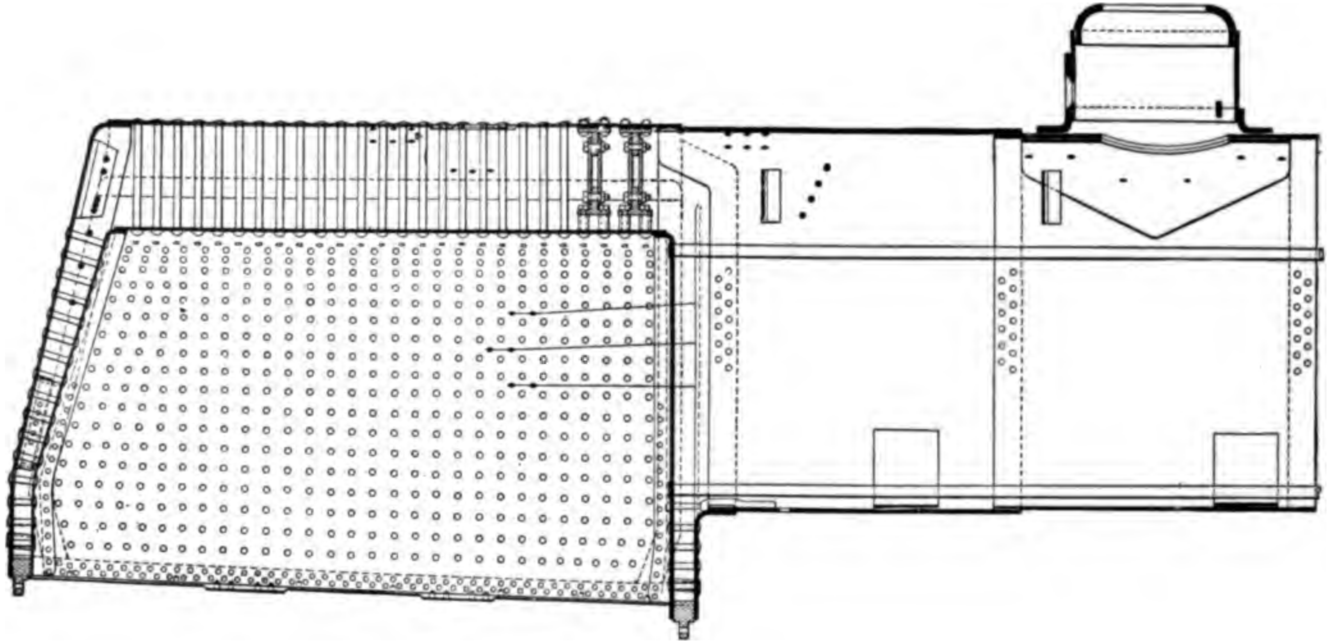


Fig. 30.

Like the vertical boiler there is an inner and an outer fire box, the inner having the same shape as the outer, except that the top is flat. The external fire box is connected to the inner by short screw stays. The space between is called the water leg. The flat top is stayed by girders or crown stays. These are sometimes attached to the shell by sling stays. The lower portions of the tube sheets are held in place by the tubes; the upper portions are stayed by diagonal stays.

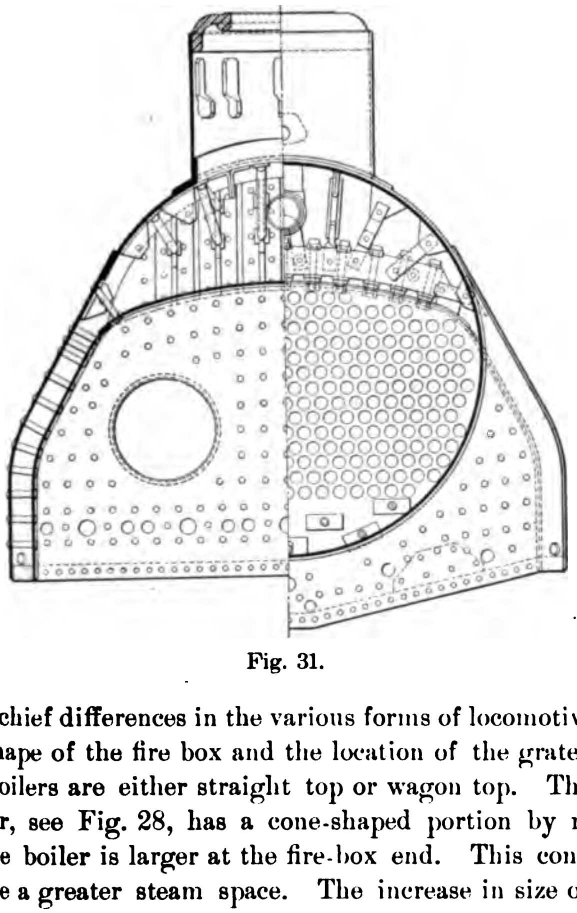


Fig. 31.

The chief differences in the various forms of locomotive boilers are the shape of the fire box and the location of the grate. Locomotive boilers are either straight top or wagon top. The wagon top boiler, see Fig. 28, has a cone-shaped portion by means of which the boiler is larger at the fire-box end. This construction is to give a greater steam space. The increase in size of boilers has raised the top so high above the rails that the wagon top is not now used extensively; the straight top, see Fig. 29, is more common.

Belpaire Boiler. The shell and fire tubes of thi boiler are practically the same as in any other fire-box b peculiarity lies in the fire box. The inner and outer fire-l are horizontal at the top, and the sides of the outer fir continued so that the space above the crown sheet is recta section. The advantage of this construction is that the holding the crown sheets and side sheets can be placed angles to the sheets. This reduces the tendency to bend under pressure.

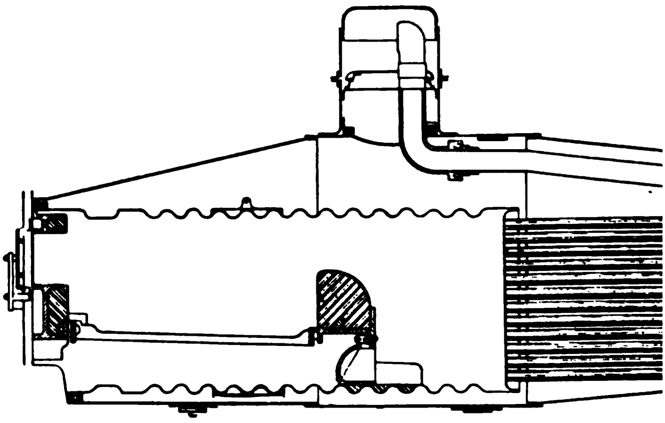


Fig. 32.

Wootten Boiler. In this type also, the fire box is portion to be considered. The size of the locomotive limited. With older types the width was limited to three feet and the length to less than seven feet. This w of the frames and the distance between the axles. By p fire box above the axles, the width was increased by a equal to the thickness of the frames or about seven inche length increased to about eleven feet. By raising the fir more and placing it above the driving wheels, the wid still further increased.

A broad, shallow fire box is required if anthraci used. The Wootten fire box, shown in Fig. 30 and 3 wide and is placed on top of the driving wheels. Former bustion chamber was placed between the end of the grat tubes, but as it was found to be unnecessary, it is not no

Lentz Boiler. The object of the design shown in Fig. 32 is to avoid the use of stays. To do this no flat plates are used, except the tube sheets and these are stayed by the tubes. The firebox is in the form of a corrugated flue similar to those in internally-fired, return-tube boilers. As this is circular it requires no stays. The shell is circular and shaped as shown in the illustration. This type has been much used in Europe, but a few have been built in this country.

FIRE-BOX BOILER FOR STATIONARY WORK.

The fire-box boiler, usually called the locomotive boiler, is often used for stationary work, traction engines, and for vessels of light draft. This type of boiler, slightly modified, is sometimes used for generating the steam for heating buildings. It is economical and durable when used with natural draft. The chief differences in construction are larger tubes because of the draft, and the changes due to method of support. A common form is shown in Fig. 33. This type has been built in large sizes for high pressure, but when so made is expensive.

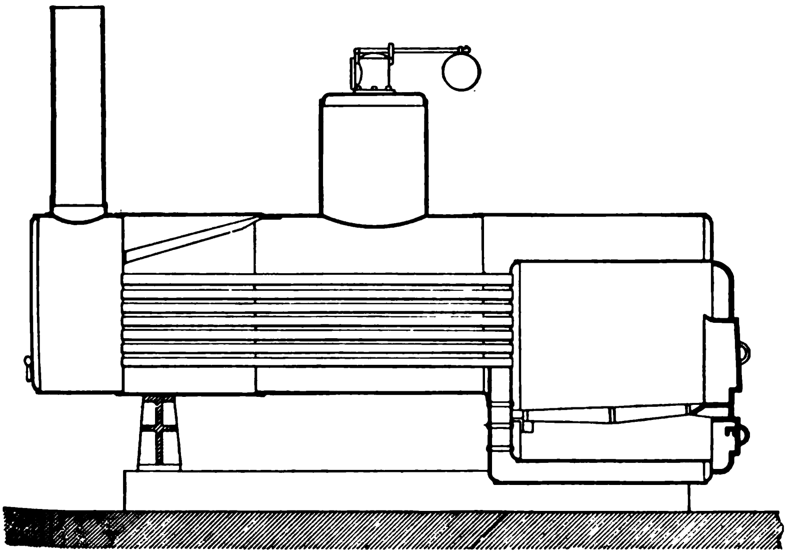


Fig. 33.

PECULIAR FORMS.

Fire-Tube Boilers, but differing from those described.

Return Tubular as Stationary. Boilers of the form shown in Fig. 34 resemble the locomotive, fire-box type, but in addition have return tubes. The hot gases reach the uptake by means of these tubes instead of passing to the chimney from the smoke-box end. Thus they combine the advantages of the fire-box type and the return-tube type without the brick furnace. The water surrounds the furnace on all sides except the front. They are built in sizes from 12 to 70 horse-power. As Fig. 34 shows the construction so clearly, further description is unnecessary.

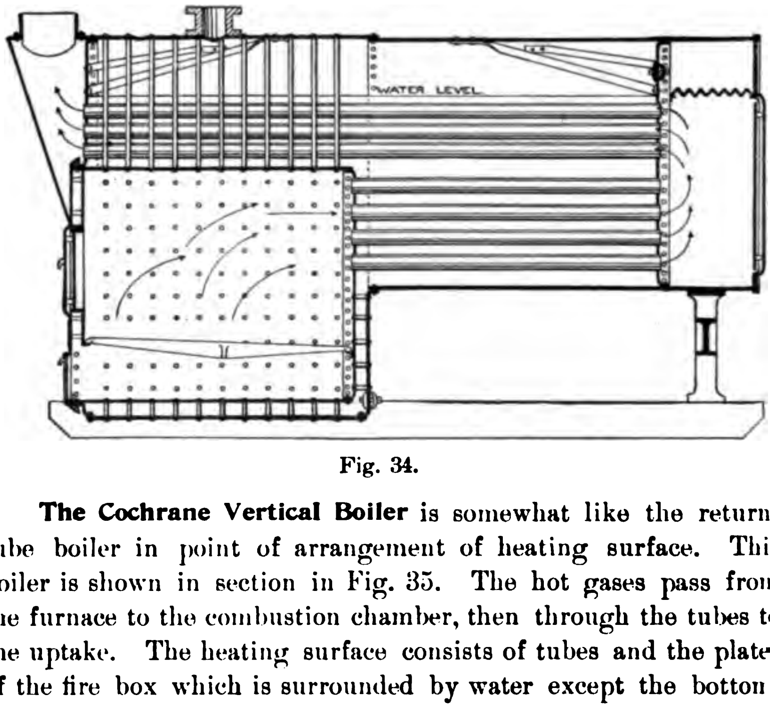


Fig. 34.

The Cochrane Vertical Boiler is somewhat like the return-tube boiler in point of arrangement of heating surface. Thi boiler is shown in section in Fig. 35. The hot gases pass fron the furnace to the combustion chamber, then through the tubes t the uptake. The heating surface consists of tubes and the plat of the fire box which is surrounded by water except the botton The crown of the boiler and of the fire box, being hemispherica require no staying. The hemispherical crown also allows a lar steam space. The flat plates (the tube plates) are held togeth by the tubes.

The Shapley Boiler, shown in Fig. 36, may be called return-flue vertical boiler. The upper portion is a reservoir fo water and steam and the lower contains the fire box. The crown sheet of the fire box is stayed to the top by through stays. The hot gases from the fire rise in the fire box, pass through short horizontal tubes to an annular space. This annular space is connected to the flue at the base by vertical tubes passing through the water space.

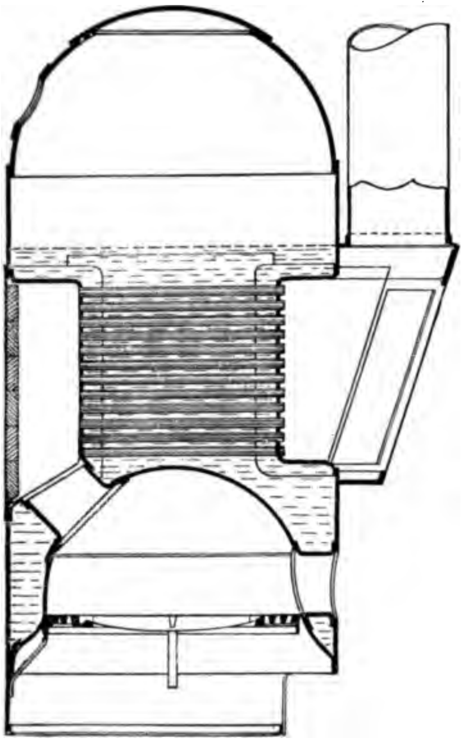


Fig. 35.

This boiler has a large combustion chamber; the fire box is surrounded by water, and the crown sheet and tubes are removed from the intense heat of the fire. This arrangement increases the heating surface, allows complete combustion and results in a durable boiler. The base is partially filled with water so that any sparks carried over will be quenched.

Robb-Mumford. This boiler resembles the through-tube internally-fired boiler (see Fig. 27) in that the fire is within a corrugated flue and the tubes lead from this flue to the rear of the boiler.

The Robb-Mumford boiler consists of two cylindric or shells, connected at each end by a neck. See Fig 3 upper drum is a steam and water drum, the water level about the middle. The lower shell is larger and is inclin one inch in twelve to increase the circulation, and facilita ing out. In this lower shell is the corrugated flue contai grate. The fi nearly fill the r portion of the shown.

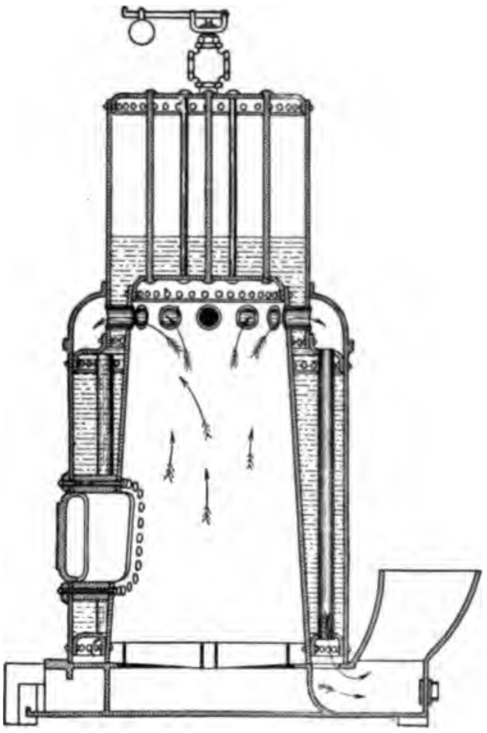


Fig. 36.

The furnace, the coal is bu surrounded by w hot gases pass the tubes to the turn between t and upper shell cape to the chim the front of th The steel casi the gases in con the drums. Tl circulation is s the arrows. T ture of water a enters the upp the steam here from the wate flows down the n forward end. circular baffle plate directs this water around the furnace to tom. The feed water enters at the rear of the steam and wat

As compared with the multitubular boiler one can re that the drums can be made much thinner on account of t diameter. The tubes are short, straight, and easily clean internal furnace does away with much of the loss from As the water is well subdivided, steam can be raised ra there is little danger of a disastrous explosion.

Directurn. The Begg's "Directurn" boiler (Fig. 38) is, in brief, a horizontal, externally-fired, multitubular boiler in which tubes conduct hot gases through the space behind the bridge.

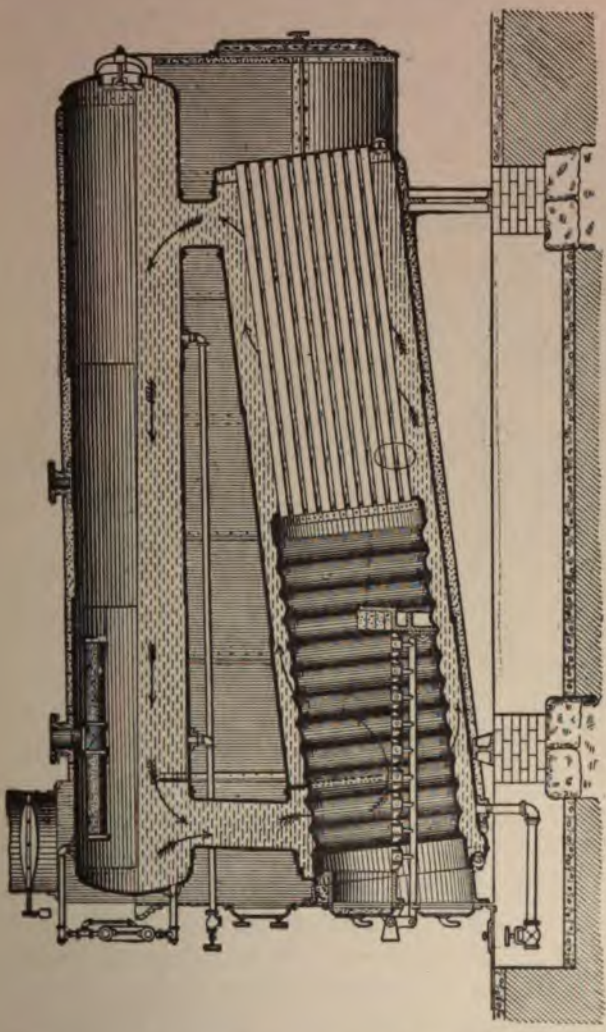


Fig. 37.

This boiler consists of a shell partly filled with 3-inch tubes. The rear of the furnace is a throat sheet in which 4-inch tubes are expanded. The other ends are expanded into the rear end plate which is made large enough for the purpose. The boiler is encased in steel plates lined with fire brick which is held in place by rods passing through the notches as shown. The manhole for entering the boiler is placed in the front head instead of in the shell as is frequently done.

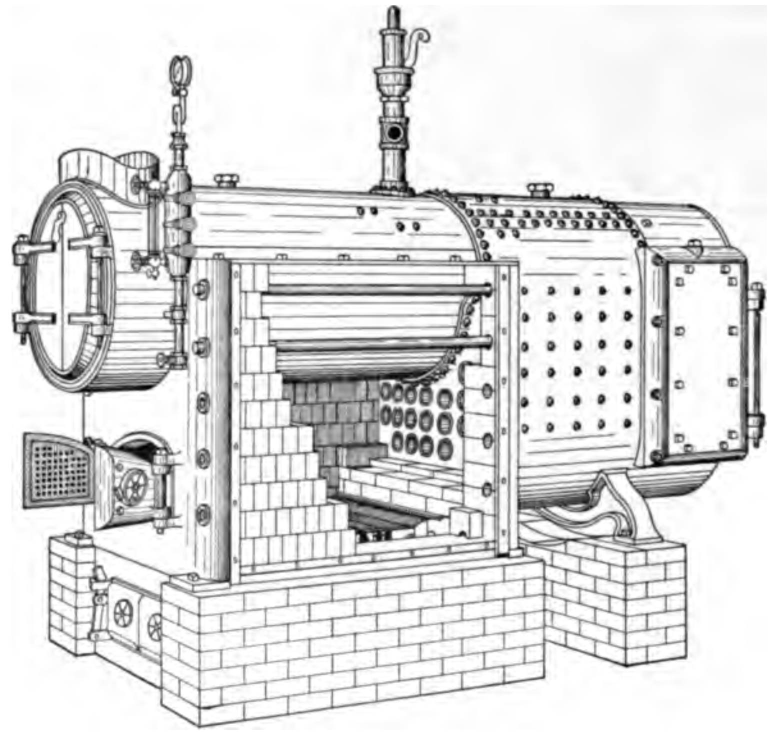


Fig. 38.

WATER-TUBE BOILERS.

The water-tube boiler differs essentially from the fire-tube. The names indicate the chief point of difference. In the fire-tube boiler, the tubes, which are surrounded with water, conduct the hot gases to the smoke box. In the water-tube, the tubes are filled with water, and the hot gases pass over and among them on their way to the chimney.

Although flue boilers and the tubular types were introduced at an earlier period than the water-tube, yet the last-named type is not a new form of steam generator. About a century ago, John Stevens invented a water-tube boiler and fitted it to a steamboat.

This boiler (Fig. 39) was a combination of small tubes connected. at one end to a reservoir. Thus the "porcupine" was one of the earliest forms. At various times since then, many ideas have been worked out both, for marine and stationary boilers. During the last fifteen years, however, the water-tube boiler has been steadily growing in favor, the chief reasons being—the necessity of higher steam pressures, greater reliability of materials, greater skill in design and workmanship, and more intelligent management.

It is not within the province of this instruction paper to discuss the relative merits of fire-tube and water-tube boilers, but a careful, impartial consideration seems to show that as far as economy of running is concerned there is but little difference. The fire-tube boiler is reliable and can be handled by those possessing comparatively little knowledge of engineering. Its chief defect seems to be the disastrous results following an explosion. The water-tube boiler, on the other hand, is safe, and suited to higher pressures, but requires greater care in management.

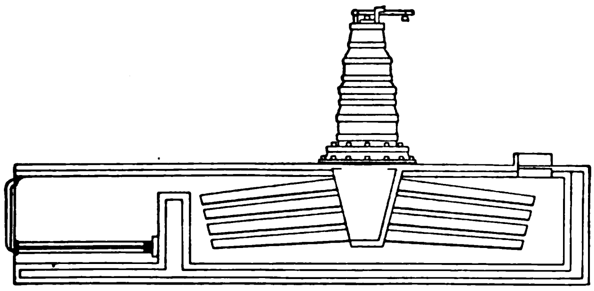


Fig. 39. Stevens Boiler.

Before discussing these boilers in detail, let us consider briefly the salient points.

Safety. Probably the greatest advantage claimed for the water-tube boiler is its safety. The boiler contains much less water than does the flue or tubular boiler and the water is divided into small masses, thus minimizing serious results in case of rupture. On account of the shape and arrangement of parts, the circulation is usually good, and no part exposed to the fire can be uncovered while there is any water in the boiler. The tubes cannot become overheated until the boiler is empty and with an empty boiler there cannot be a serious explosion.

Rapidity in Raising Steam. The many small streams into which the water is divided as it passes through the furnace greatly facilitate the absorption of heat. Because of the small streams and the rapid circulation, the water is converted into steam in a very short time. Several hours (usually five to seven) are required to raise steam to working pressure in a tubular boiler, while in many water-tube boilers, steam can be raised to over 200 pounds pressure in less than half an hour.

Durability. Most water-tube boilers are so designed that no seams are exposed to the fire or hot gases. The seams are the weakest part of a boiler, and as strains due to unequal expansion concentrate at such points, leaks or even ruptures are liable to occur. In the water-tube boiler, the joints between tubes and tube sheets are not in the direct path of the hot gases.

Loss of Heat. The loss of heat will evidently be reduced to a minimum if the heating surfaces are such that the heat readily passes through to the water. The small diameter of the water tubes (2 to 4 inches) allows the use of thin metal which does not hinder the transmission of heat. The rapid circulation in the water-tube boiler prevents the accumulation of sediment which is a poor conductor of heat. Still further, dust and dirt does not readily collect on the convex surface of water tubes, but the *inside* of fire tubes soon become choked with soot unless cleaned frequently. See Fig. 40.

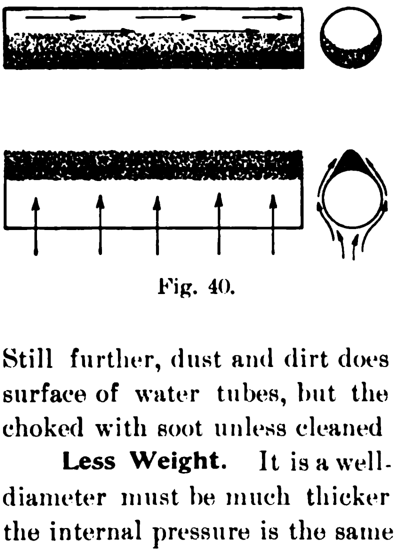


Fig. 40.

Less Weight. It is a well-known fact that a cylinder of large diameter must be much thicker than one of small diameter when the internal pressure is the same. The thickness of the shell of a fire-tube stationary boiler is not excessive, because of the moderate diameter; but in the return-tube marine boiler, the shell plates for 250 pounds pressure would be about 1⅞ inches thick. The difficulty of working such thick plates and their great weight render the cylindrical boiler unsuitable for high pressures. The small tubes and drums of the water-tube boiler may be made quite thin even for very high pressures. In general, it may be said that for the same capacity and pressure, the weight of a water-tube boiler is only about two-thirds that of a fire-tube.

CLASSIFICATIONS.

Many attempts have been made to classify water-tube boilers. By some writers a classification based on circulation, or on the principle of operation, is claimed to be superior to any division according to construction. Therefore, they divide them into classes as follows—boilers with limited circulation; boilers with free circulation; boilers with accelerated circulation.

In the first part of this Instruction Paper, is given a classification according to features of construction. No classification is altogether satisfactory because boilers overlap into other divisions; a water-tube boiler may be sectional, of the double-tube type, have horizontal tubes, straight tubes, and free circulation. In order to have some sort of classification, and as no discussion will be entered into regarding relative merits, the classification given on page 6 will be here adopted and followed as closely as conditions will permit.

Water-tube boilers are divided into two great classes—horizontal and vertical. Under these heads come sectional and non-sectional, straight-tube and curved-tube, and single-tube and double-tube. If the tubes are nearly horizontal, such as is the case of the Babcock and Wilcox, Root, etc., the boiler will be called horizontal. If the tubes are vertical, or nearly so, as in the Wickes, Stirling, etc., the boiler will be classed as vertical.

Although most boilers can be classified as outlined on page 6, there are a few of such peculiar construction and arrangement that they must be placed by themselves under "Peculiar Forms." These are described without any further attempt at classification.

As it is impossible to discuss all makes of boilers, a few representative forms will be considered as types of their respective classes. No attempt will be made to choose any make as being the best, because many conditions must be considered in selecting a boiler. The boilers described, except in a few cases, are now used extensively in either stationary or marine work.

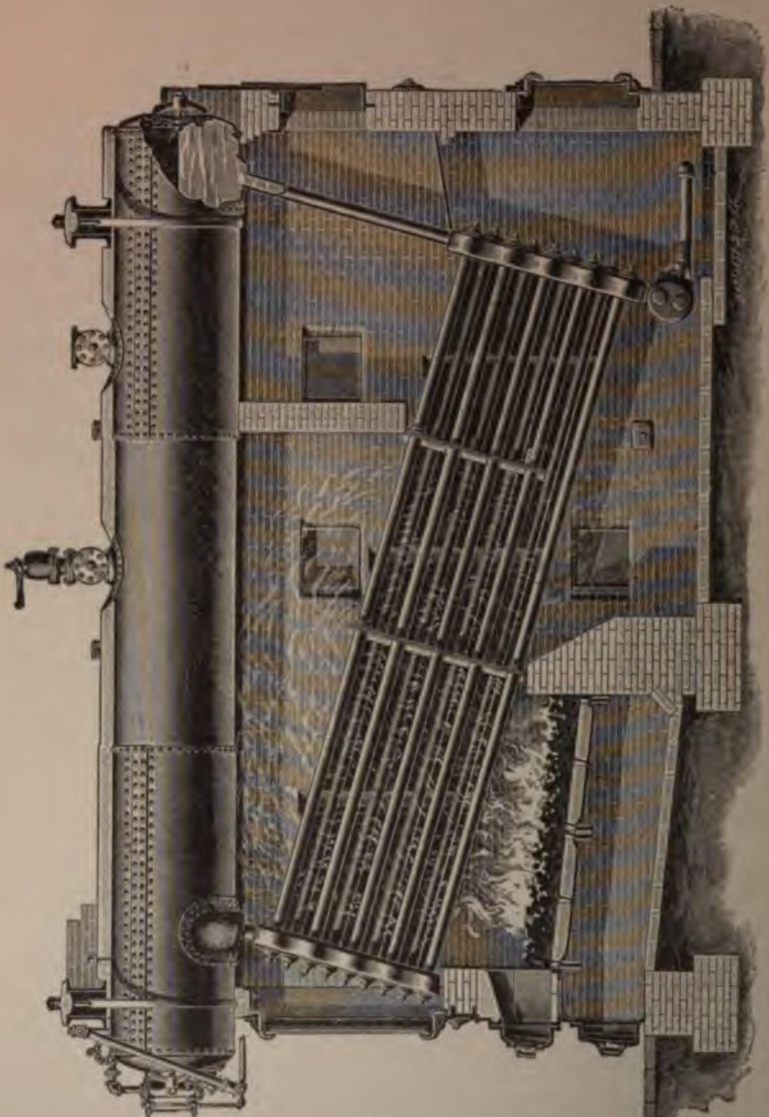


Fig. 41.

HORIZONTAL WATER-TUBE BOILERS.

BABCOCK AND WILCOX.

**ıbes Nearly Horizontal—Steam and Water Drum Horizontal—
Straight-Tube—Single-Tube—Sectional.**

struction. This boiler consists of a large number of lap-
vrought-iron, 4-inch tubes connected to each other and to
ıtal steam and water drum. The arrangement of the parts
in Fig. 41 which is a side
a much-used form of this
Each tube is expanded into a
f the form shown in Fig. 42.
tubes in a vertical row enter
and this vertical row is in-
ıt of the others, as shown in
Thus it is readily seen that
sectional boiler. Fig. 43
o the "staggered" arrange-
he tubes. In the back side
ont header, and in the front
the rear header, holes are
ıto which are expanded the
bes. In the front side of
er a flanged hole opposite
e is fitted with a hand-hole
The details of construction
n in Fig. 44. The tops of
lers are connected to the
d water drum by short tubes and the same construction is
connecting the mud drum to the rear header.

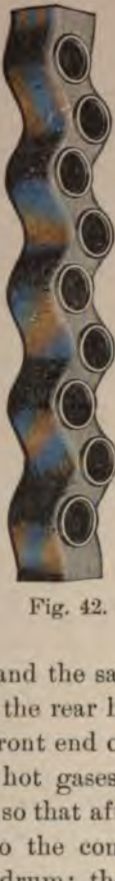


Fig. 42.

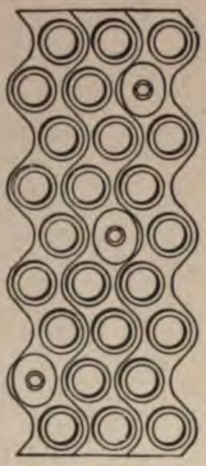


Fig. 43.

ration. The grate is at the front end of the boiler under
ıer end of the tubes. The hot gases from the fire are
y division plates and bridges, so that after rising from the
ey pass between the tubes to the combustion chamber,
under the steam and water drum; the gases then pass
d among the tubes, and after rising a second time pass off
imney. In this way, the direction of the currents of hot
t all times almost at right angles to the tubes, thus im-
ıpon them instead of passing parallel to the heating sur-

faces, as in the case of fire tubes. As the gases impinge three times against the staggered tubes, the heating surface is very efficient.

Circulation. The feed water enters the steam and water drum through the pipe shown in Fig. 44. It is thus heated before it mixes with the hot water in the boiler. As the water in the tubes becomes heated, it rises to the higher end where it is partly converted into steam; a column of water and steam rises through the header to the drum in which the steam and wate become separated. The cooler water at the rear of the steam an water drum flows down into the lower end of the tubes and as becomes heated rises. Thus there is a continuous circulation.

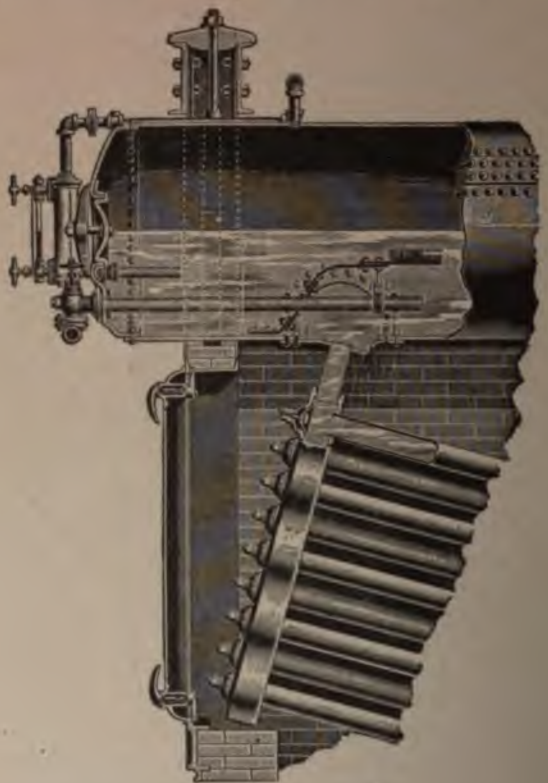
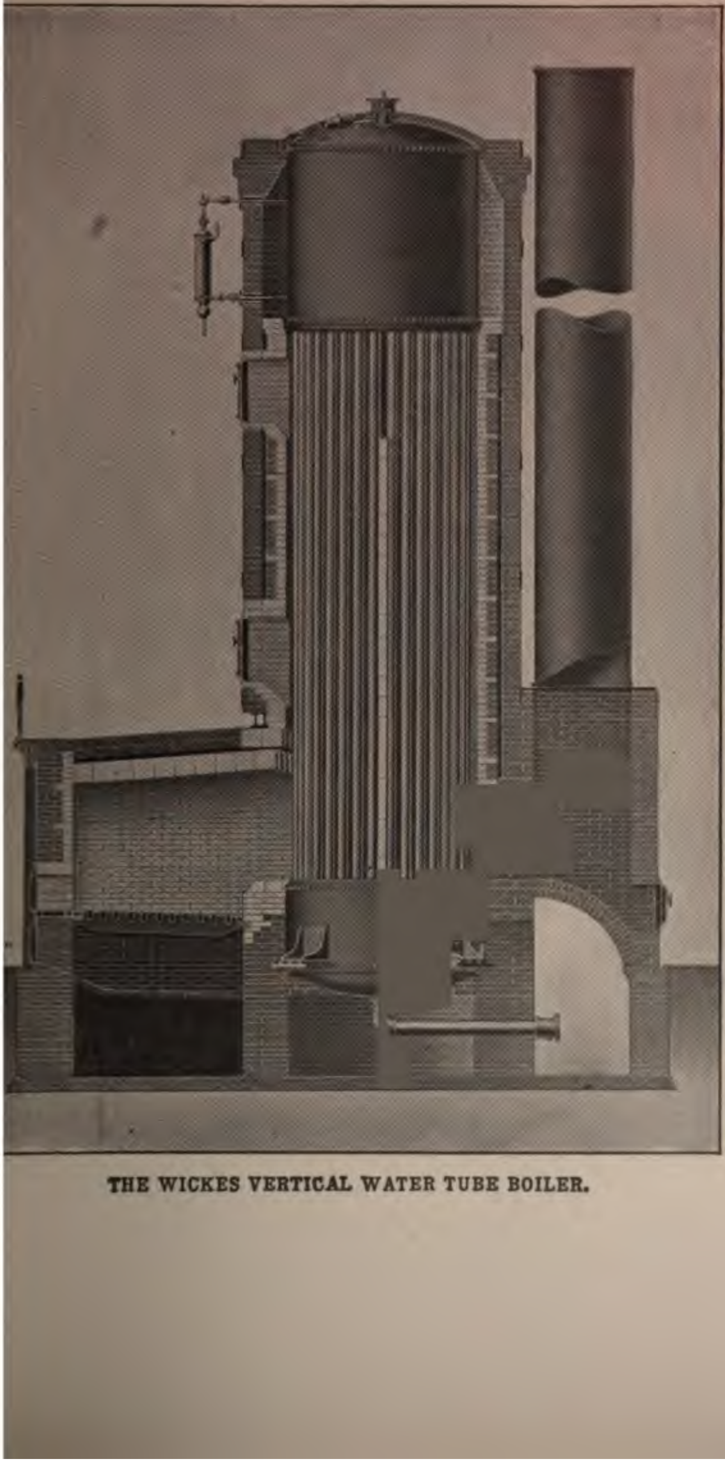


Fig. 44.

Steam is taken from the rear end of the steam and water drum. The solid matter in the water is not deposited on the tubes



THE WICKES VERTICAL WATER TUBE BOILER.

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ASTOR, LENOX
TILDEN FOUNDATIONS

ecause of the rapid circulation; it falls to the mud drum from hich it is blown out.

The marine form of this boiler has a cross drum, that is, the rum is at right angles to the tubes instead of parallel to them. t is similar in form to the cross-drum types used for stationary ork. This form is used in case there is not sufficient head room.

ROOT.

Vater Tubes Nearly Horizontal—Steam and Water Drums Horizontal —Straight-Tube—Single-Tube—Sectional.

The above brief outline indicates that the Root water-tube iler is, in its main features, like the Babcock and Wilcox. In ct the difference is in detail construction only. Fig. 46 ws the general appearance en a part of the brickwork emoved. It will be seen that re is a large steam drum oss type) at the top in addi- n to the small steam and ter drum over each section.

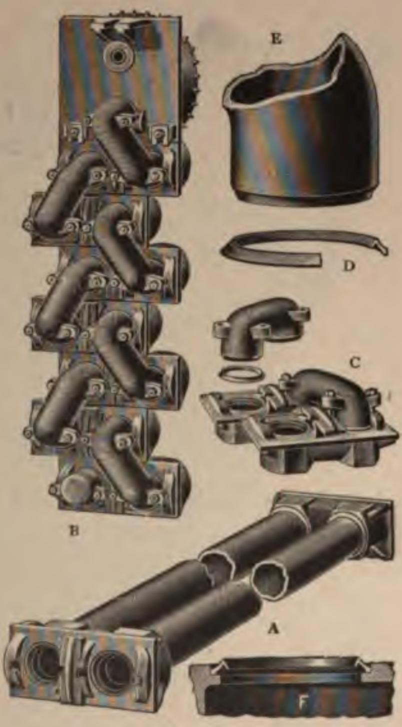

Fig. 45.

Construction. The Root ter-tube boiler is composed 4-inch lap-welded wrought- n tubes. These tubes are anded into cast iron headers shown in A, Fig. 45. A ver- l section is formed by plac- one pair upon another as wn at B, Fig. 45. One tube each pair is connected to one ve it by a flexible bend, by ns of which is obtained an interrupted circulation from bottom to the top of the tion. A metallic packing ng (see C, D, and E, Fig. 45) insures a tight joint between the nd and the header. F, Fig. 45, shows an enlarged end of a bend.

To form the boiler several of these vertical sections are placed side by side. These vertical rows are not rigidly connected because the lower tubes being nearer the fire expand more than those above.

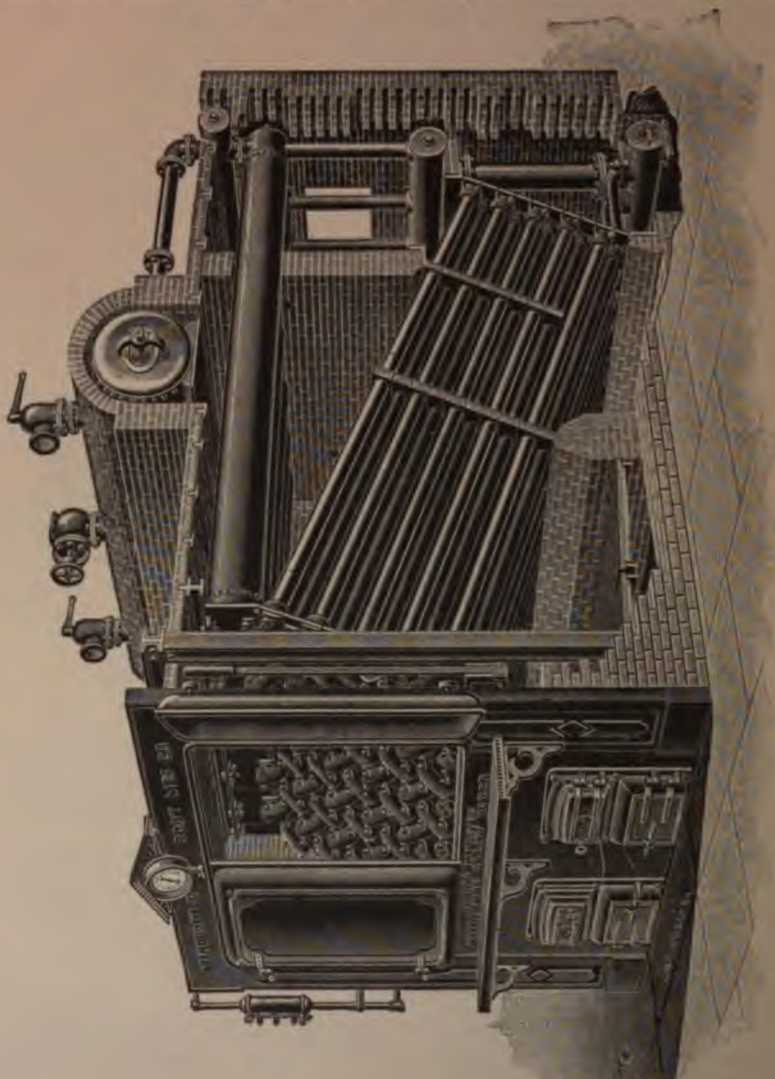

Fig. 11.

Circulation. Each section has its overhead drum into which the water and steam is discharged from the tubes. At the rear of the boiler and at the end of each steam and water drum, a v[illegible] tical pipe leads to a cross drum beneath; this drum is a common reservoir for all the sections. The feed water enters this drum and meets the hot water coming from above. The mixing of the water results in a temperature which prevents any trouble from unequal expansion. The cross drum (reservoir) is also connected by vertical pipes to another drum which is below and parallel to it; this is the mud drum. From the feed reservoir, the mixture of feed and circulating water descends to the mud drum in which the solid impurities are left. The circulating water then flows from the top of the mud drum into the lower end of the tubes. As these tubes are surrounded by hot gases, the water becomes heated and rises through the tubes to the steam and water drums. This heated water contains bubbles of steam which leave the water and collect in the steam drum. The water flows through the steam and water drum and descends to meet the entering feed water. The water level is at about the middle of the steam and water drums.

The hot gases from the fire pass among the tubes three times in practically the same manner as in the Babcock and Wilcox boiler.

WORTHINGTON.

Water Tubes Nearly Horizontal—Steam and Water Drum Horizontal —Straight-Tube—Single-Tube—Sectional.

Construction. This form of boiler is much the same in principle and operation as the Babcock & Wilcox boiler, but the parts are differently proportioned and arranged; see Fig. 47. The furnace extends under the entire boiler, and the tubes are set over it close together in oppositely inclined series. No flame walls or baffle plates are used.

Boilers up to 125 H. P. are usually made to fire at the end as shown in Fig. 47, in which the tubes extend across the furnace viewed from the front, and the steam and water drum is at right angles to the tubes. In the *side-fired* boilers the tubes extend from front to back, and the steam and water drum from side to side; this arrangement is better adapted for large units and for setting in battery. The tubes of each vertical row are expanded into straight headers which contain seven or eight tubes. See Fig. 48. Opposite each tube is a hand hole. These headers are arranged close together, forming the boiler enclosure.

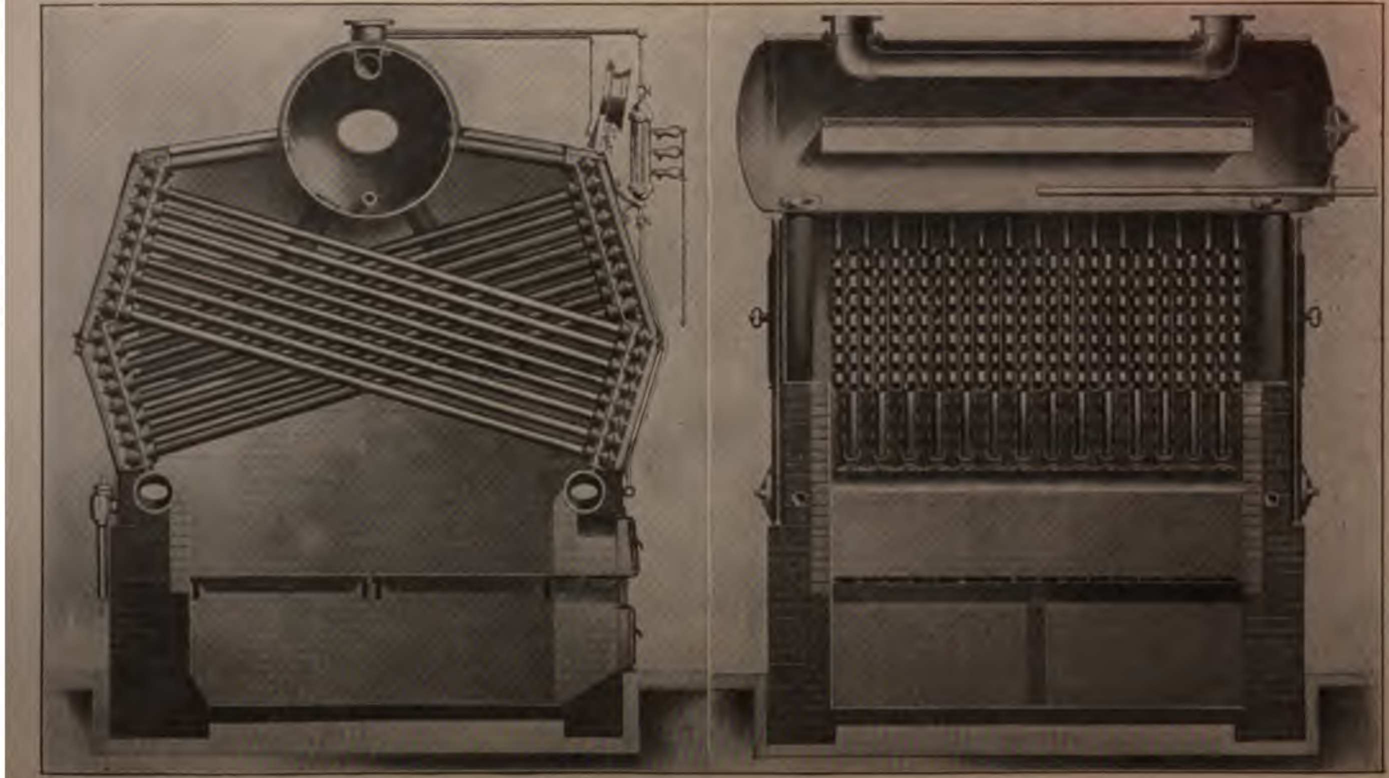

Fig. 47

Circulation. The feed water enters the steam and water drum and the circulation carries it down to the mud drums through large circulating tubes which are outside of the furnace. See Fig. 48. From the mud drum it enters the lower series of headers and rises through the inclined tubes over the fire into the upper headers.

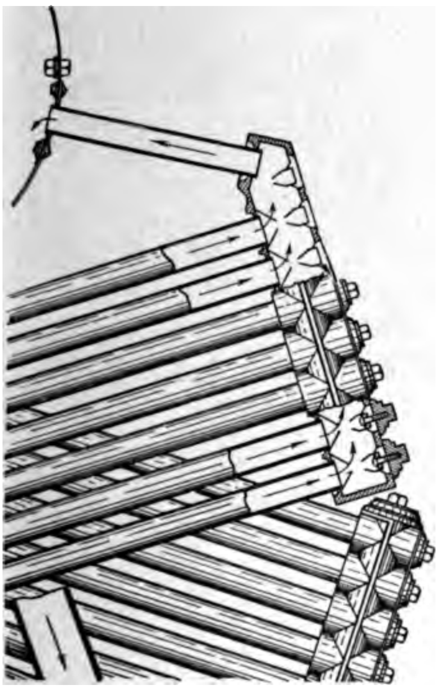

Fig. 48.

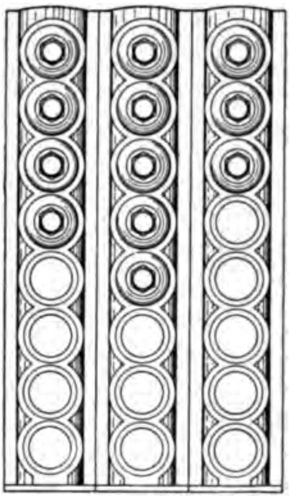

Fig. 49.

The water now containing bubbles of steam enters the steam and water drum by means of short tubes shown in Figs. 47 and 48.

The covering for this boiler is an iron casing, no brick being used except to enclose or line the furnace.

HEINE.

Water Tubes Nearly Horizontal—Steam and Water Drum Parallel to Tubes—Straight-Tube—Single-Tube—Non-Sectional.

Construction. The Heine water-tube boiler is not a sectional boiler. Instead of being expanded into small headers grouped to form a boiler, all the tubes are expanded into the inside plates of

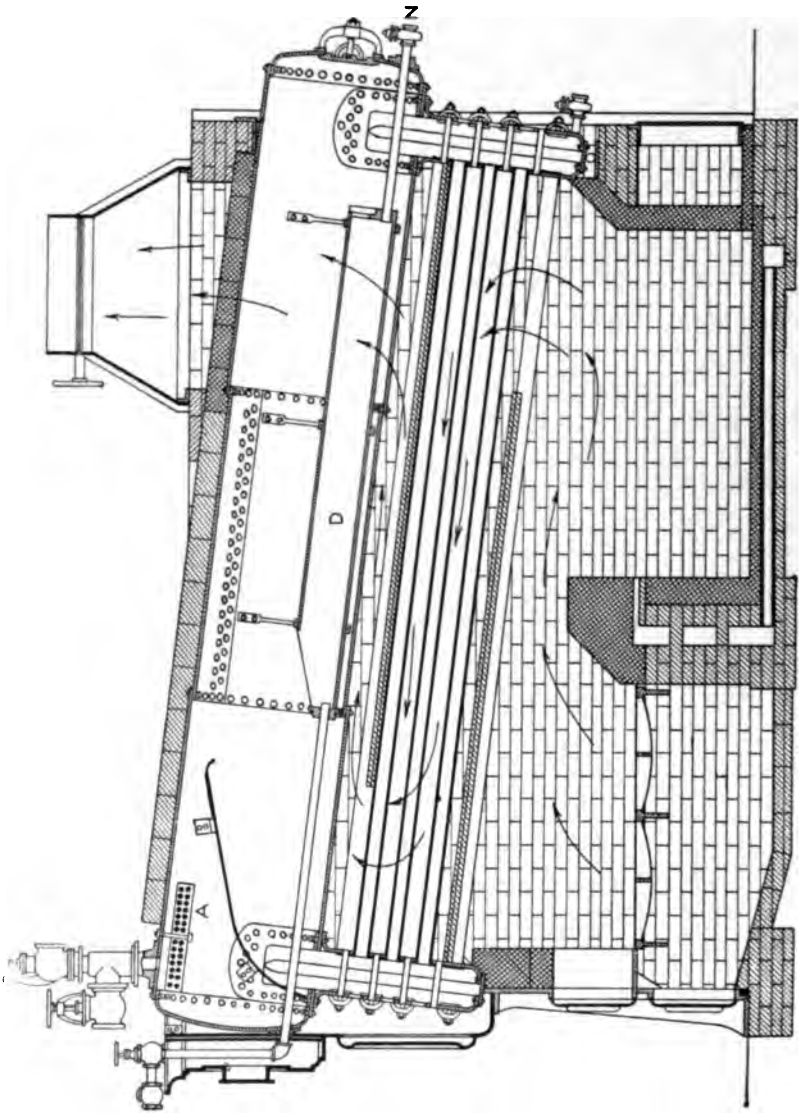

Fig. 51.

a water leg at each end. The construction of this water leg is shown in Fig. 50. It is composed of two parallel plates flanged and riveted to a butt strap. The plates are strengthened by short hollow screw stays similar to those used in the water-leg construction of fire-box boilers. At the top, the water leg is curved and joined to the steam and water drum by riveting. Opposite each tube is a hand hole for cleaning or replacing a defective tube.

Circulation. The feed water enters at the front of the steam and water drum and flows into the mud drum D, from which it passes to the rear header with much less velocity. The water is warmed while passing through the pipe leading to the mud drum, and as it flows slowly through the mud drum it deposits its sediment. The accumulated sediment is blown off by means of the blow-off pipe N. The water, as it becomes heated in the mud drum, rises and passes to the front of the mud drum, from which it flows in a thin sheet to the rear of the steam and water drum and to the rear water leg. From the rear water leg, it enters the tubes in which it is partially converted into steam. The mixture of steam and water enters the higher end of the drum from the water leg, and as there is but a thin layer of water in the steam and water drum, the steam readily rises through it. A deflection plate prevents water from being carried to the perforated steam pipe A.

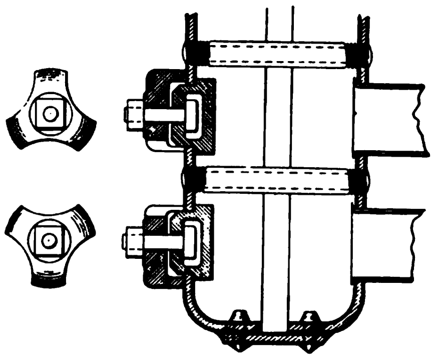

Fig. 50.

The flow of hot gases from the fire is directed by light tile placed on the upper and lower rows of tubes as shown in Fig. 51. The hot gases flow nearly parallel with the tubes instead of across them as in the Babcock and Wilcox.

ATLAS.

Water Tubes Nearly Horizontal—Steam and Water Drums (Cross Type) Horizontal—Straight-Tube—Single-Tube—Non-Sectional.

This make of water-tube boiler does not need a full description as Figs. 52 and 53 show both the general arrangement of

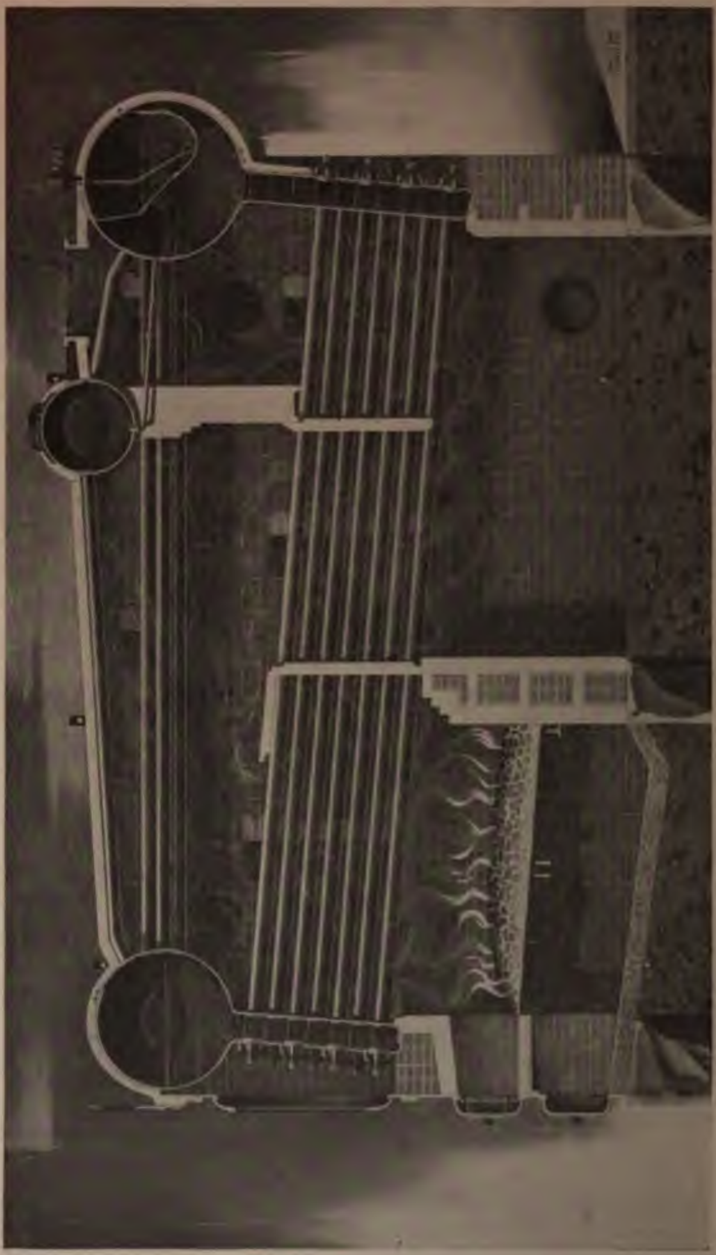

Fig. 52.

parts and the details of water-leg construction. The general description of the Heine boiler is applicable to this type. A few points of difference, however, should be pointed out.

There are three drums running crosswise the tubes. The front and rear drums are made of the same plates as the water legs. This is shown in the illustrations. The reasons for this method of construction are that it gives a "throat" area of about 80 per cent of the area of the leg and prevents all seams from coming in contact with the furnace gases. The two drums are connected on the water line by equalizing tubes. In the rear drum, a water purifier receives the feed water which passes down the rear leg, then through the tubes to the front leg. In the last portion of the tubes, much of the water is converted into steam which flows through the front drum and the superheating tubes to the small upper drum. The water flows through the equalizing tubes to the rear drum and joins the current of feed water.

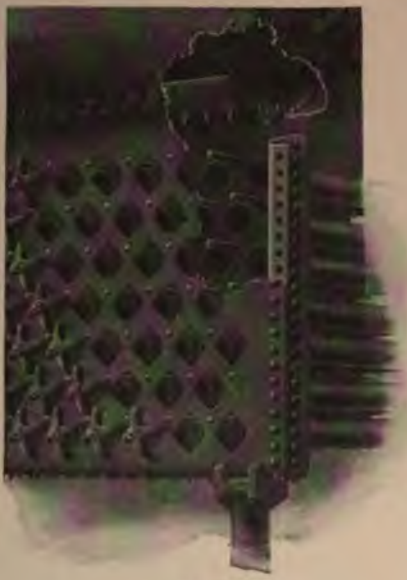

Fig. 53.

The front drum is made 36 inches in diameter, the middle drum 24 inches, and the rear drum 42 inches. The tubes are 4 inches in diameter and the longest are 18 feet in length.

MOSHER.

Water Tubes Nearly Horizontal—Steam and Water Drums (Cross Types) Horizontal—Curved-Tube—Single-Tube—Non-Sectional.

The chief differences in appearance between this boiler and those already described are shorter tubes, making a more compact boiler, and the curved tubes. This type is more often used in

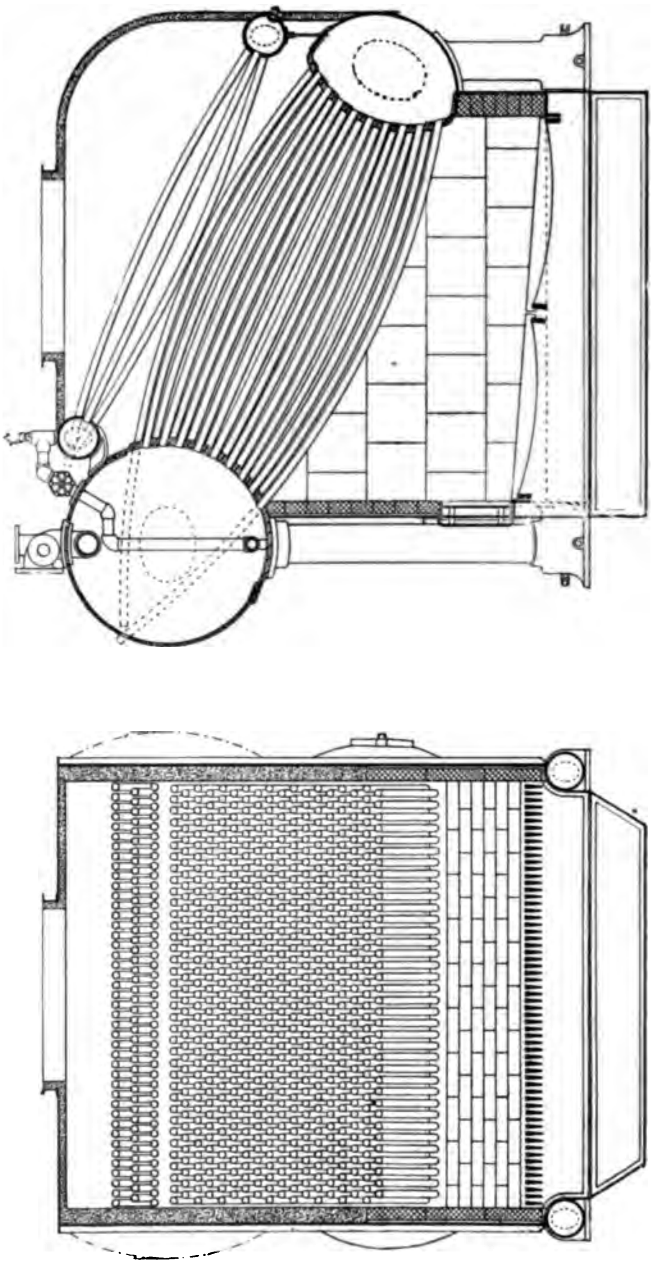

Fig. 54.

marine than in stationary work. The boiler consists of a large steam and water drum connected to a smaller water drum by slightly curved tubes. The steam drum is supported by two large circulating pipes (one at each end) which are connected by other pipes to the water drum. Thus the circulation is down these pipes and along the pipe at the bottom (see Fig. 55), up to the water drum and from thence to the steam drum by the tubes which are in contact with the hot gases.

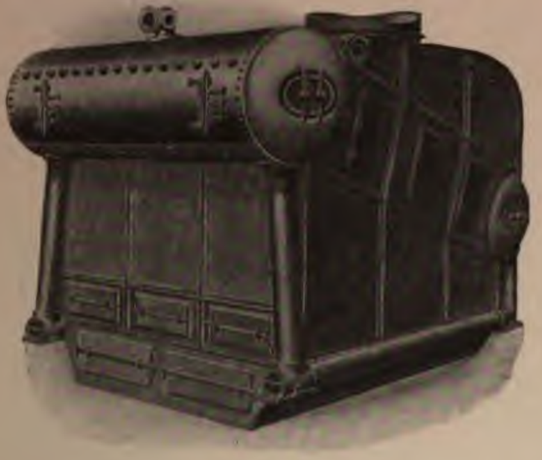

Fig. 55.

The feed-water heater, shown in Fig. 54, consists of two small drums connected by tubes. The parallel dotted lines in the steam drum of Fig. 54 show how tubes are removed and replaced. Fig. 55 shows the row of plugs for this purpose. These plugs are illustrated in Fig. 56. Each plug is a conical-headed bolt, having a short piece of copper tube, a washer, and a nut. The conical head and the copper tube are inserted in the hole until the washer is in contact with the outer surface of the drum. The nut is then screwed up, thereby flaring the end of the copper tubing as shown.

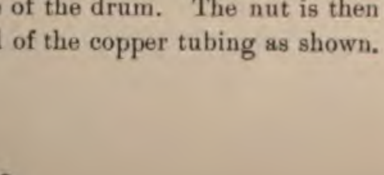

Fig. 56.

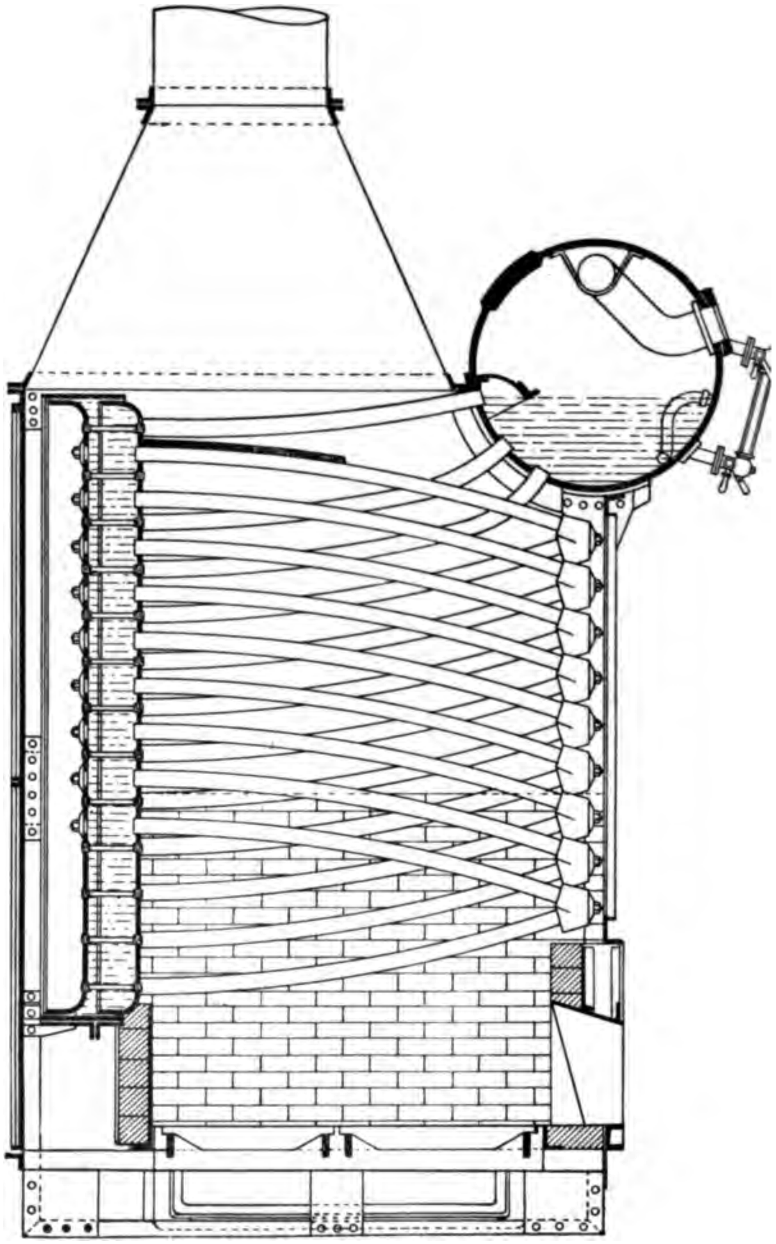

Fig. 57.

The steam pressure on the conical head increases the tightness of the joint.

THORNYCROFT-MARSHALL.

Water Tubes Nearly Horizontal—Steam and Water Drum (Cross Type) Horizontal—Curved-Tube—Single-Tube—Non-Sectional.

The Thornycroft-Marshall non-sectional boiler consists of a large horizontal steam and water drum, a vertical water box or header, and the generating tubes. Like the Mosher, the tubes are curved slightly, but the header is a distinct difference.

The general features of construction are shown in Fig. 57. The steam and water drum, sometimes called the separator barrel, is simply a cylinder with dished ends. The water level is about one-third the diameter of the cylinder. The tubes, which are 3¼ inches in diameter, are connected in pairs to a junction box at one end and to a water box or header at the other end. Thus each pair forms a unit, but the two tubes of the unit are not in the same vertical plane. The upper tube enters the header as high as possible and the lower ones enter low down, thus giving considerable upward slope. From near the top of the water box, three rows of tubes lead to the separator barrel as shown in Fig. 58. The water box is very simple, the flat plates are stayed by short hollow screw stay-bolts. The junction boxes are not restrained in any way; this construction, combined with the slight curve of the tubes, allows free expansion. The slight curve also allows the tubes to enter the separator barrel and the water box at right angles so that they may be expanded in place.

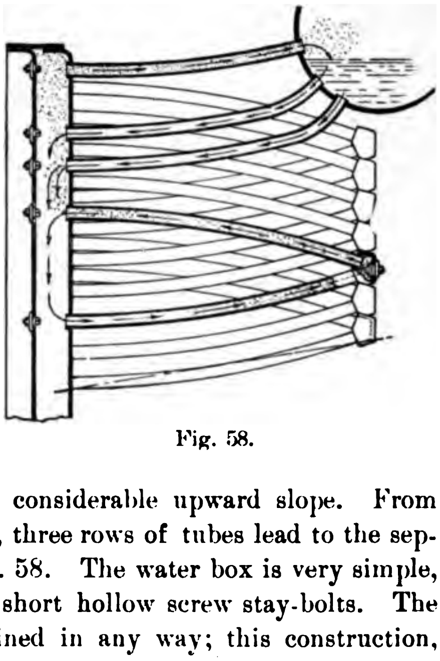

Fig. 58.

Circulation. The feed water enters the steam and water drum and then passes to the water box through the two lower sets of tubes. See Fig. 58. The water enters the lower ends of the various pairs

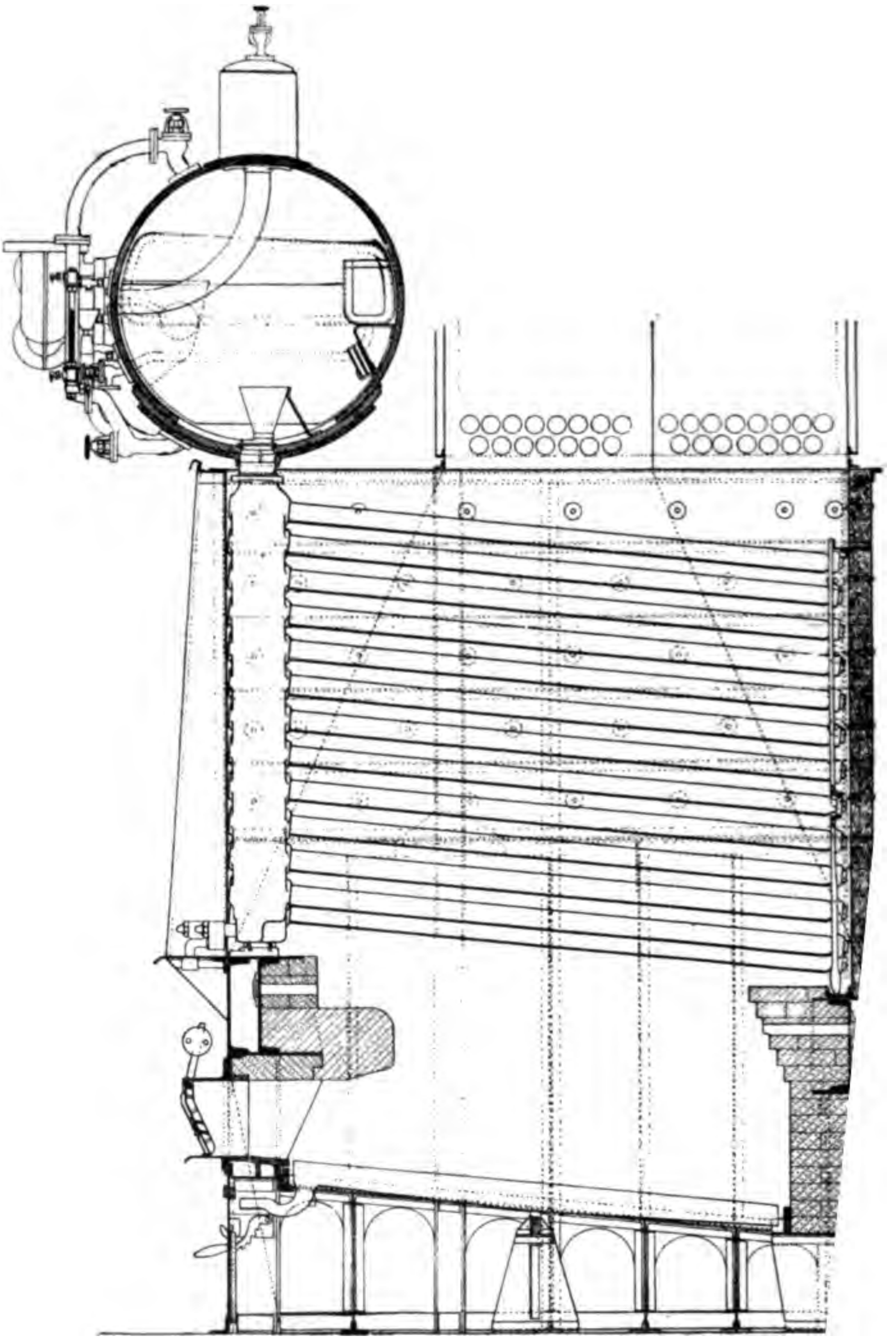

Fig. 59.

of tubes, as shown in Fig. 58, and rises in the tubes while in contact with the hot gases from the furnace. The mixture of steam and hot water then enters the header from which it passes to the steam and water drum by means of the highest row of tubes. The difference in height of the two tubes of a unit insures good circulation. A baffle plate prevents the water from splashing to the steam pipe.

The hot gases pass upward among the tubes which cross so frequently that they take almost all the heat from them.

NICLAUSSE.

Water Tubes Nearly Horizontal—Steam Drum Horizontal—Straight-Tube—Double-Tube—Sectional.

This boiler differs essentially from those already described in that it is of the *double-tube* type. In general, it consists of a number of elements which form a vertical header, to which tubes are connected. The tubes are set at an angle of about 6 degrees to the horizontal. Above the elements is a transverse steam and water drum which is in communication with the headers. The general arrangement of parts is shown in Fig. 59.

Construction. The interesting features of this type of boiler are the design and construction of the tubes and headers. To increase the circulation the principle of the "Field" tube is employed. In this construction, the outer, or generating, tubes ($3\frac{1}{4}$ inches in diameter) are closed at one end. Each generating tube contains an inner circulating tube which is $1\frac{19}{32}$ inches in diameter.

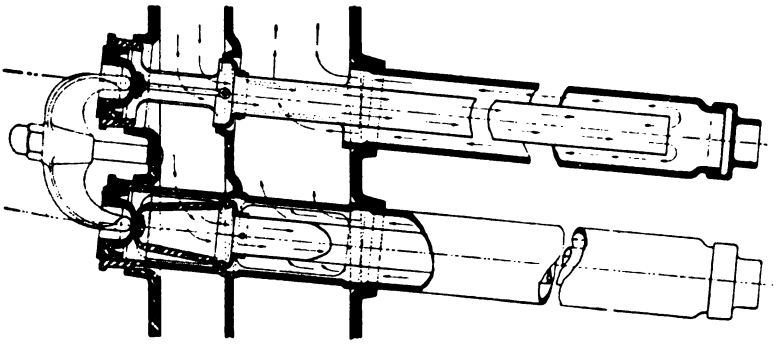

Fig. 60.

This tube is open at both ends. The closed ends of the generating tubes are supported by resting in holes in a plate or rack at the rear of the boiler. The forward end of the circulating tube is attached to a cap which screws into the outer end of the generating tube. A recess in this cap provides a bearing for an arch bar which spans two tubes, keeps them in place, and is itself secured by a nut on a bolt which is screwed into the header. See Fig. 60.

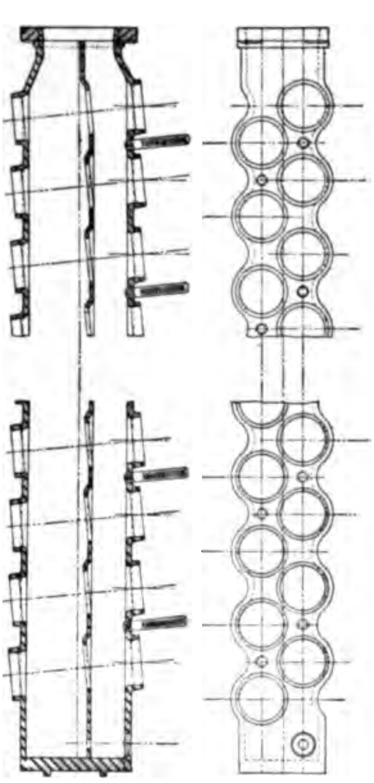
Fig. 61.

The front end of the generating tubes is of peculiar shape. To allow the water to enter the circulating tubes, and to fasten the tubes to the header without expanding them, each generating tube is provided at the open end with two cone-shaped portions; these are about eight inches apart. The first cone fits into a taper hole flanged outward in the front face of the header, and the second cone fits a similar hole in the rear face of the header. Both the holes and tubes are ground to the same size and taper. About midway between the cones, a third expanded portion occupies the tube hole in the diaphragm or middle plate of the header. See Fig. 60. The portion of the tube within the header is called the "lantern". At this point the tube is cut away so that water may freely enter the tube, the openings being above and below. In Fig. 60, the upper tube is in its normal position, but the lower tube has been turned through 90 degrees to show the construction.

To stand high steam pressures, the elements of the headers are made of wrought steel and are sinuous in shape. Fig. 61 shows the shape of the header and the positions of the tubes.

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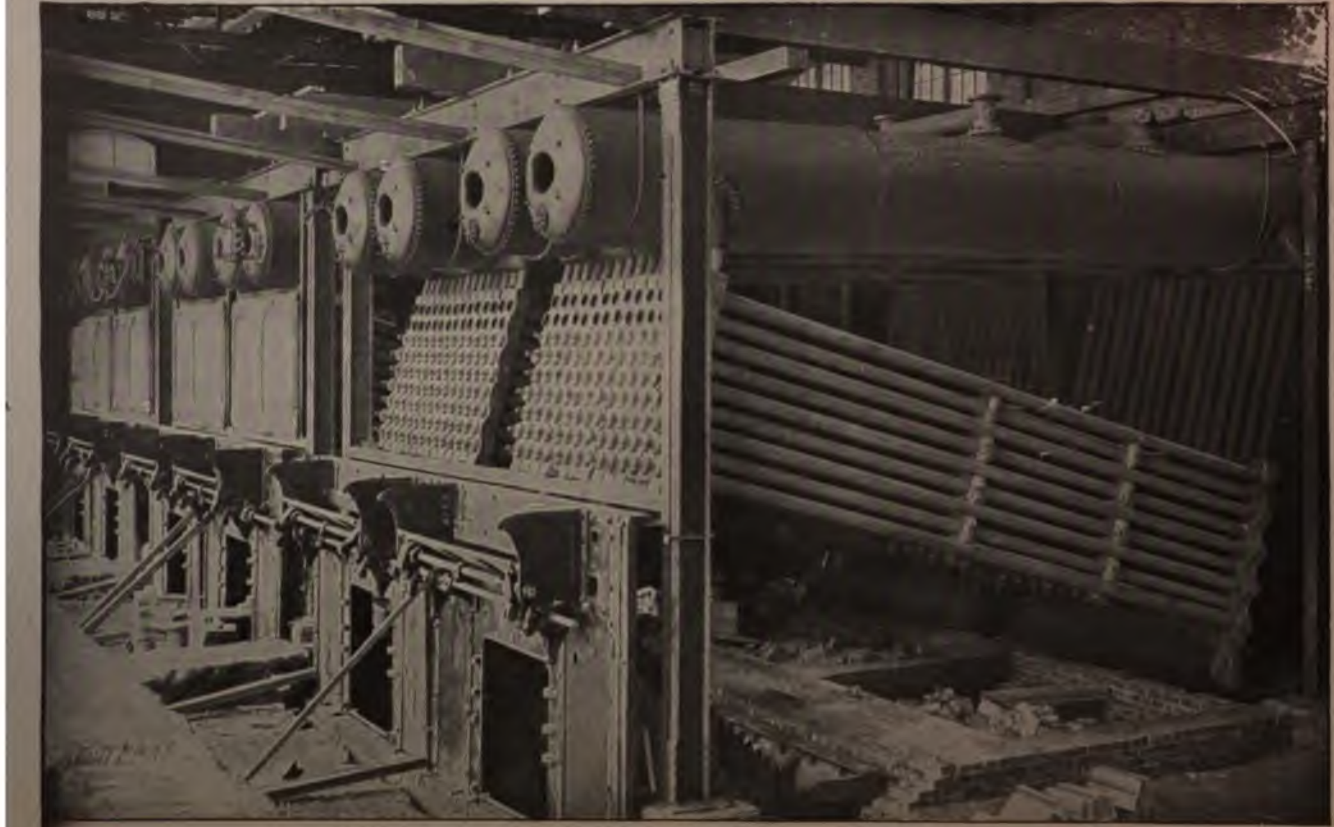


1000 Horse Power Babcock and Wilcox Boilers in Process of Erection.

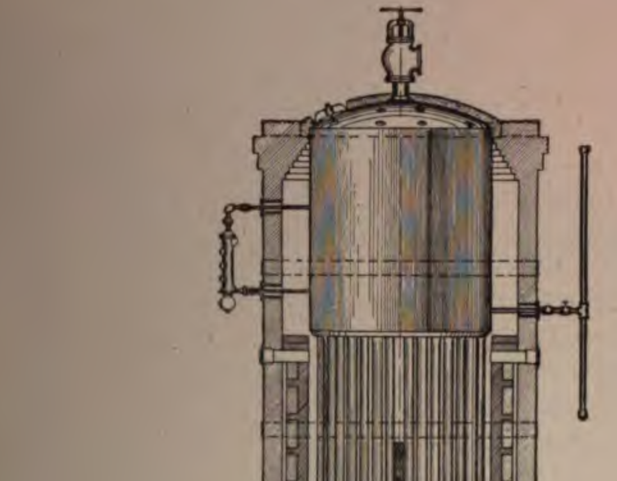


Fig. 62.

Each element contains 24 tubes in two vertical rows of 12 each In the middle of the headers, there is a diaphragm for dividing the interior. The front passage serves as a "downcomer" for the water, and the rear is the "upcomer", or riser, for the mixture of steam and water.

The lower ends of the headers are closed, and the upper ends flanged to connect with the steam and water drum, which is 42 inches in diameter.

Circulation. Fig. 60 gives an idea of the direction of circulation. Water from the drum descends in the front compartment of the header, flows into the circulating tubes, *which communicate with the front compartment only*, and after flowing the length of the circulating tubes, enters the generating tubes. The water then comes back through the annular spaces in the generating tubes to the rear compartment of the header, because the *generating tubes communicate with the rear compartment only;* while in the annular space it is partially evaporated. The mixture of steam and water then rises to the drum.

VERTICAL WATER-TUBE BOILERS.

WICKES.

Water Tubes Vertical—Straight-Tube—Single-Tube—Non-Sectional.

Let us now consider a water-tube boiler having vertical tubes. Fig. 62 shows the general arrangement of the parts of the Wickes vertical water-tube boiler. At the top is a cylindrical steam and water drum into which the upper ends of the vertical tubes are expanded. At the bottom is a cylindrical mud drum of the same diameter as the upper drum. The tubes are straight and plumb when in position; they are arranged in parallel rows with a clear space between rows to admit a small hoe to remove any soot that may accumulate on the tube sheet of the mud drum.

The tubes are divided into two compartments by heavy firebrick tile. The tubes in the section next the furnace are called "risers"; those in the rear are the "downcomers," because the heated water rises to the steam drum through the front tubes, and the cooler water flows down those in the rear. The feed water is introduced into the upper drum. The direction of flow of hot

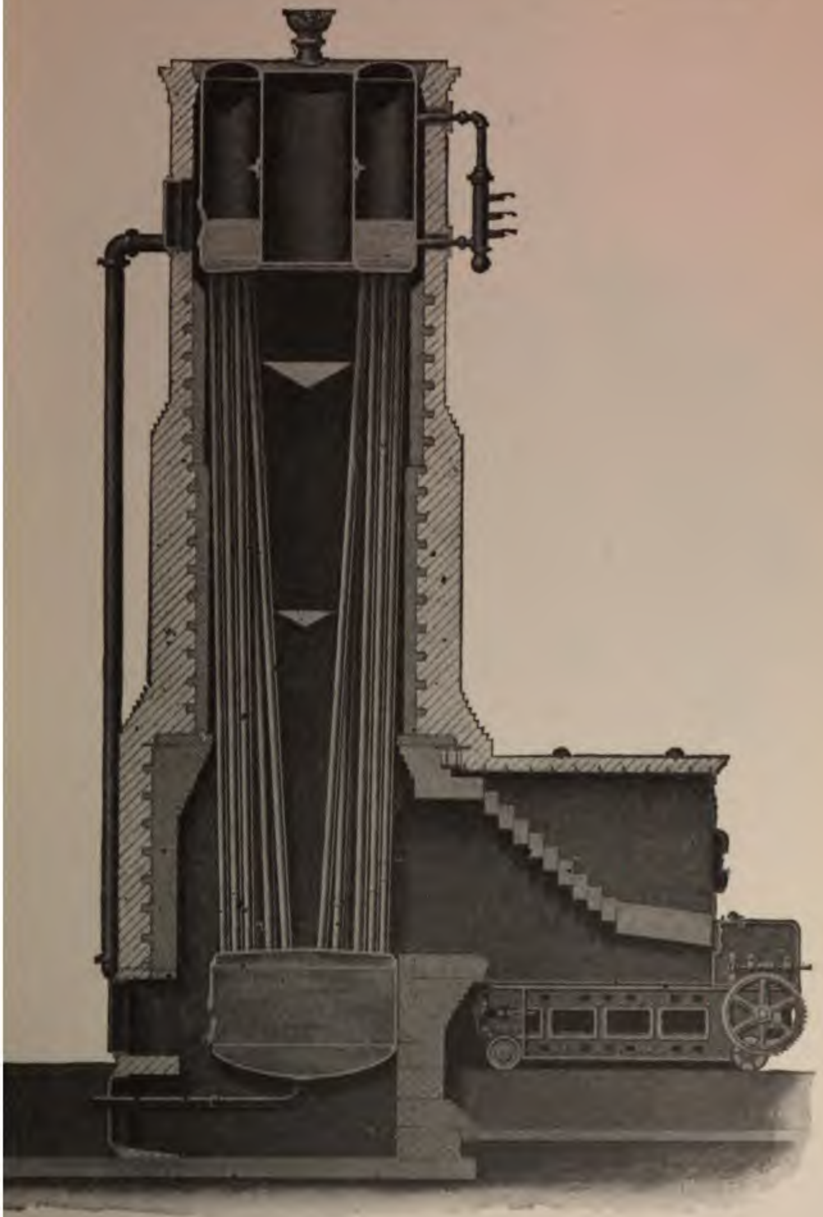


Fig. 63.

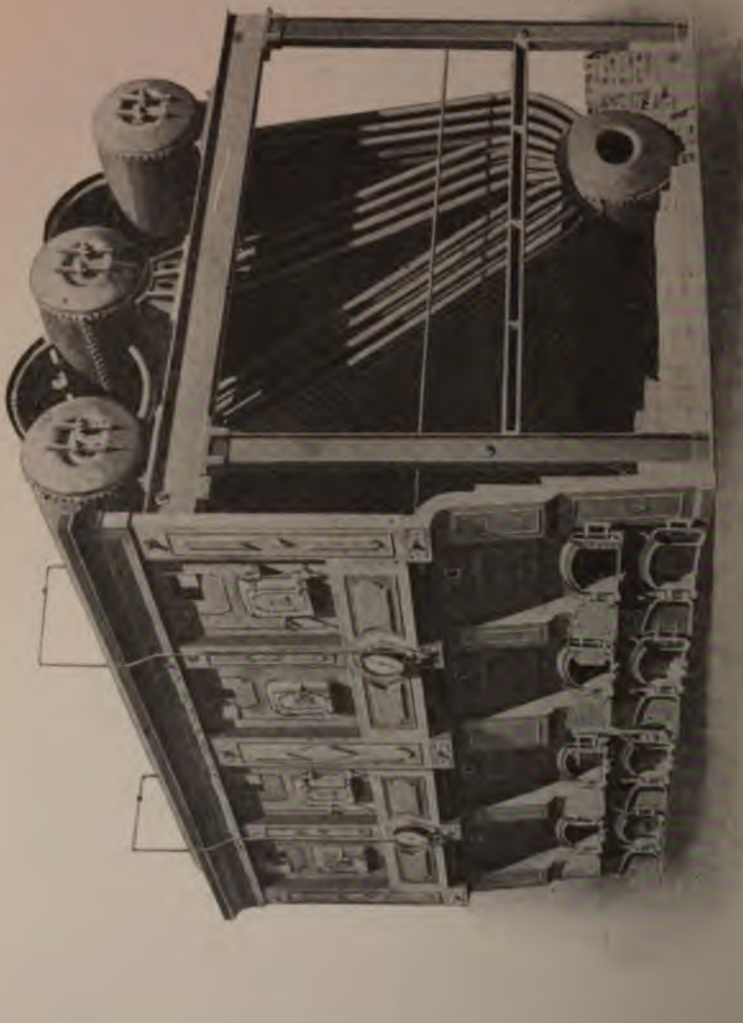


Fig. 64.

is the same as that of the water. A baffle plate in the steam ater drum directs the water to the downcomers.

he furnace is external and built entirely of brick. The hot from the fire come in contact with the tubes without passing gh a combustion chamber.

CAHALL.

lar Steam and Water Drum—Water Tubes Vertical—Straight-Tube—Single-Tube—Non-Sectional.

he Cahall vertical water-tube boiler consists of an annular and water drum, a cylindrical mud drum, and 4-inch vertical The generating tubes connect these two drums and are within the brick setting. An external circulating pipe also cts the two drums. As this pipe is filled with comparatively ater and the generating tubes with a mixture of hot water team, the circulation is positive and rapid. The feed water the steam and water drum, flows down the external pipe to ud drum and then rises in the generating tubes to the steam ater drum.

he fire is in a brick furnace at one side of the boiler as in Fig. 63. The hot gases rise among the tubes. The an- form of the steam drum makes the central space conical; in pace several deflecting plates, or baffles, cause the hot gases to ut among the tubes. After heating the water in the tubes ot gases pass through the opening in the steam and water coming in contact with the metal containing the steam horoughly dries the steam and in many cases slightly super it.

he steam drum and also the mud drum are equipped with ing manheads. The steam drum also has several handholes e in removing and replacing tubes.

STIRLING.

Tubes Nearly Vertical—Steam and Water Drums Horizontal—Curved-Tubes—Single-Tube—Non-Sectional.

he Stirling boiler, shown in Fig. 64, consists of three cylin- steam and water drums at the top, and a mud drum at the n. The lower drum is connected to the upper drums by three sets of tubes which are curved slightly at the ends. The curved tubes allow for expansion and make it possible to have the tubes enter the drums radially.

The feed water enters the rear steam and water drum and coming in contact with the hot gases just before they enter the uptake, becomes gradually warmed. This heating causes most of the sediment to fall to the mud drum from which it may be blown out at intervals. The mud drum is protected from the intense heat of the furnace by the bridge wall.

Each set of tubes are separated from the others by partition walls or baffles of fire-brick tile so that the gases from the furnace pass along the entire length among the first set of tubes; they are then guided downward among the second set and after rising again among the tubes of the third set, escape to the chimney. By thus having a long passage a large proportion of the heat is taken from the gases before they go to the chimney. The fire-brick arch just above the furnace insures an even distribution of the gases and promotes combustion; the arch heats the entering air to a high temperature, thus reducing the liability of chilling the tubes by an inrush of cold air.

Steam is taken from the middle drum which is set a little higher than the others in order to obtain more steam space and drier steam. The boiler is surrounded on the rear and two sides by the brick setting; the front is of cast iron or of pressed steel. Numerous openings in the brickwork allow entrance for cleaning.

This type of boiler is flexible and adapted to cramped places as it can be made broad with little height or high with small floor area. All parts are either cylindrical or spherical in shape and of wrought metal. The curved tubes reduce the strains resulting from unequal expansion and contraction.

MILNE.

Water Tubes Vertical—Steam and Water Drum Horizontal—Curved Tube—Single-Tube—Non-Sectional.

This boiler (Fig. 65) is in many respects similar to the Stirling (Fig. 64), but an inspection of the two illustrations will show several differences. In the Milne boiler there is but one steam and water drum and the tubes are vertical with a slight curve at

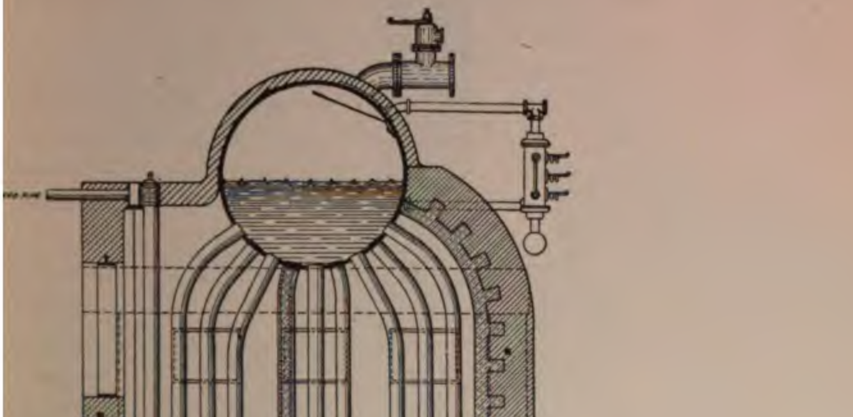


Fig. 65.

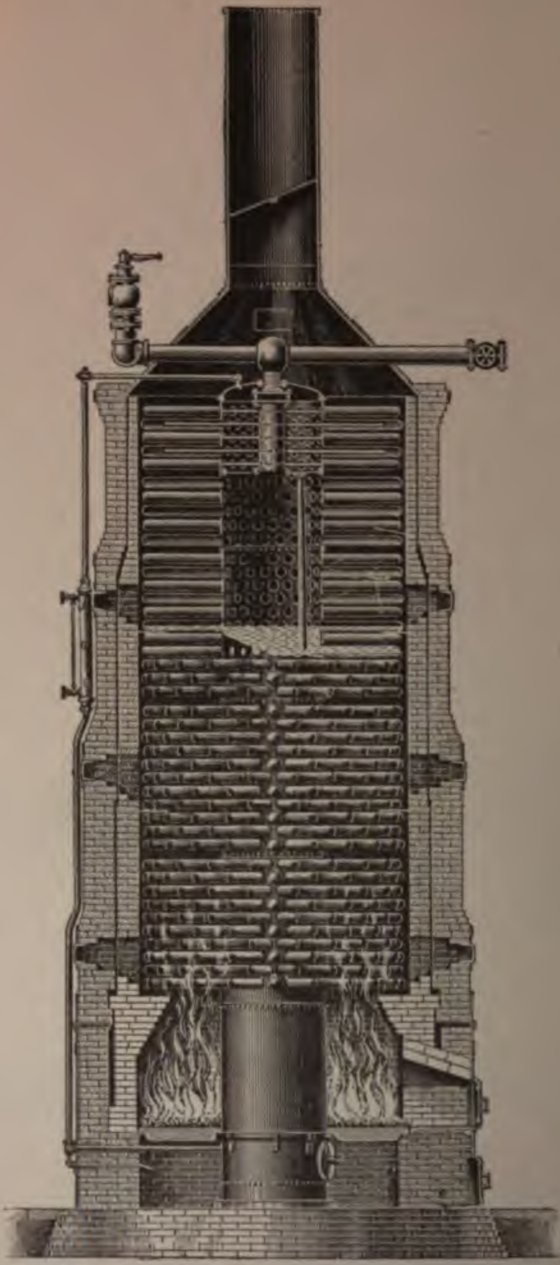


Fig. 66.

ends. The hot gases are guided by division plates or tile so t they traverse 65 feet of tube-heating surface before they enter flue. The tubes, being vertical, do not become covered with e ash, nor do they become clogged with sediment and scale.

Circulation. The feed water enters the row of tubes at the reme left and flows downward to the mud drum. It then rises it becomes heated in the hotest generating tubes and enters the am drum as steam and water. This method of feeding keeps cold feed water out of the steam drum, and as the cold tubes ntaining the feed are placed in the path of the escaping gases, t little heat escapes to the chimney.

PECULIAR FORMS.

HAZELTON OR PORCUPINE.

Water Tubes Horizontal—Steam and Water Drum Vertical—Straight-Tube—Single-Tube.

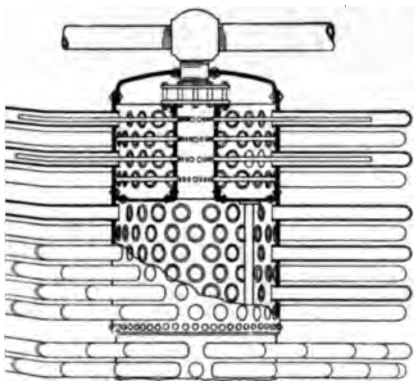


Fig. 67.

The Hazelton water-tube boiler differs in many ways from e boilers thus far described. Like most water-tube boilers it consists of a steam and water drum and water tubes, but the central standpipe is vertical and the short horizontal tubes radiate from the central drum. According to our classification it is not a vertical water-tube boiler because the tubes are horizontal, also, it is not a horizontal boiler as in general appearance it is vertical.

The grate is circular and formed around the central m which rests on a circular cast-iron foundation. Above the te, the central drum forms part of the heating surface and is the am reservoir; below the grate it is the mud drum, which may be tered by means of a manhole just below the grate. As shown Fig. 66, the standpipe above the fire is provided with radial bes. The appearance of these tubes gives the name "porcupine".

The standpipe is about three feet in diameter for large boilers. The tubes are about four inches in diameter, and two and one-half feet long, the number varying with the capacity of the boiler. The outer ends of the tubes are closed and hemispherical, and the inner ends expanded into the standpipe. These tubes are free to expand and contract without bringing any strain on the boiler.

Steam is taken from the top of the central drum. To get dry steam, small pipes are inserted as shown in Fig. 67. The steam passes up into the small tube at the top of the standpipe and then through the small pipes to the ends of the generating tubes. It then flows back through the generating tubes to the annular space and from thence to the steam pipe. The feed pipe enters the mud drum and extends upward nearly to the water line; it then returns nearly to the level of the grate, terminating in a spraying nozzle.

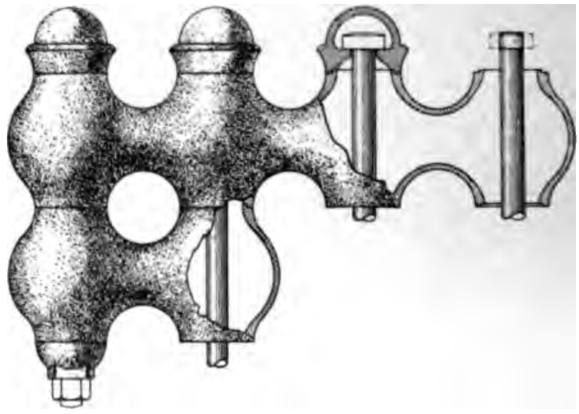


Fig. 68.

This type of boiler may be enclosed in a brick setting as shown in Fig. 66 or by a sheet steel covering lined with fire brick.

HARRISON.

Sectional Hollow Cast-Iron Spheres Instead of Tubes.

All boilers thus far described have employed tubes as a means of dividing the water into small masses in order to make the heating surfaces more effective. In the Harrison Safety Boiler (Fig. 69) tubes are not used; instead, the water is contained in hollow ast-iron spheres, called units. These units, see Fig. 68, are rranged in vertical rows, called slabs, which are suspended side y side, about one inch apart, from an iron framework. The rickwork setting is merely a covering to keep the hot gases in ontact with the units; it does not support the boiler, and can be epaired without disturbing the units.

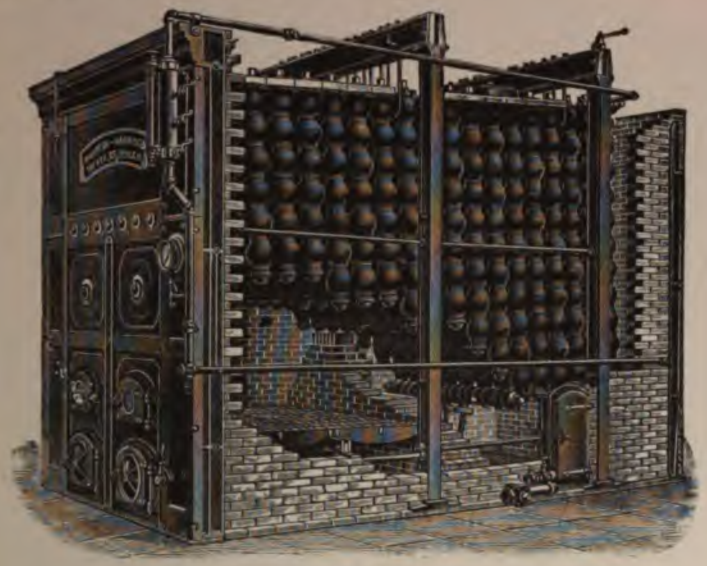


Fig. 69.

The use of units in place of tubes combines great strength l a large heating surface. They are strong because small and erical and on account of the division of the water into small sses, the heating surface is effective. The units are held to- her by long bolts which pass through the centers as shown in g. 68. The machined faces make a steam-tight joint without king. This boiler requires the same fittings as other boilers.

The great advantage of this boiler is safety. From the con- uction, it is apparent that rupture cannot extend beyond the it; thus disastrous explosions cannot occur. They are claimed be durable, economical, rapid steamers, and easily handled. he capacity can be increased by merely adding more slabs.

MANHATTAN 74TH ST. POWER STATION, NEW YORK.
Showing Carey's Magnesia Pipe and Boiler Covering.

BOILER ACCESSORIES.

FURNACES.

The furnace varies in shape, size and detail with the type of boiler and the kind of fuel. It consists of a mouth piece with doors, grate bars, bridge and ash-pit; some furnaces have special arrangements for the removal of ashes, clinkers, etc., for cleaning and for smoke prevention. There are some general conditions that every furnace should have, in order that the highest efficiency be attained. There should be a uniform and abundant supply of air to the under side of the grate. This is easily obtained in most furnaces; exceptions being the Cornish, Lancashire, Return Tube and Scotch Marine boilers, since they are internally fired.

When smoky fuels are used a small amount of air is necessary on the surface of the coal, for a few minutes after firing. This air is generally supplied through a grid or draft plate in the fire door. As the air thus admitted is usually cold, the amount must be small to prevent cooling of the furnace and checking of combustion.

In order to prevent radiation, many boilers have a large casting for a furnace front. In the case of an internally fired boiler, this casting conceals the rings of rivets which join the flues to the end plates. A mass of brickwork at the front of the boiler is likely to keep moisture in contact with the end plate, and conceal outward bulging, due to defective stays or plates; and is likely to cause corrosion. A coating of non-conducting material which can easily be removed is preferable. The furnace should be so arranged as to allow **Complete Combustion.** In an externally fired boiler, this is done by making the space above the fire sufficient to allow the gases to become completely burned. The average distance between the grate bars and crown sheet is usually about two feet. If the distance is increased, some of the effect of the heat is lost; if the distance is small, the plates are likely to be damaged, and the combustion impaired. In the internally fired boiler, the combustion and radiating spaces are often sacrificed for a large grate area. If the bars are placed too high, the combustion chamber must be used in order to insure complete combustion.

The locomotive crown sheet is from four to six feet above the grate bars.

The **Furnace Door** is usually of cast iron and is supplied with a circular or sliding draft plate which admits air to the top of the fire. It is usually protected by a perforated wrought iron plate, bolted to the casting, an air space of two or three inches being allowed.

Grate. Grates should not be larger than the fireman can conveniently clean and fire. A narrow grate should not be as long as a wide one, and if it is more than four feet wide two furnace doors should be used. The grates are often inclined slightly to aid in firing and in order that the space above and below may be used to the best advantage.

The **Grate Bars** are usually made of cast iron, as this material is cheap and in most instances lasts as well as wrought iron. They are made in various forms, according to the fuel and shape of the

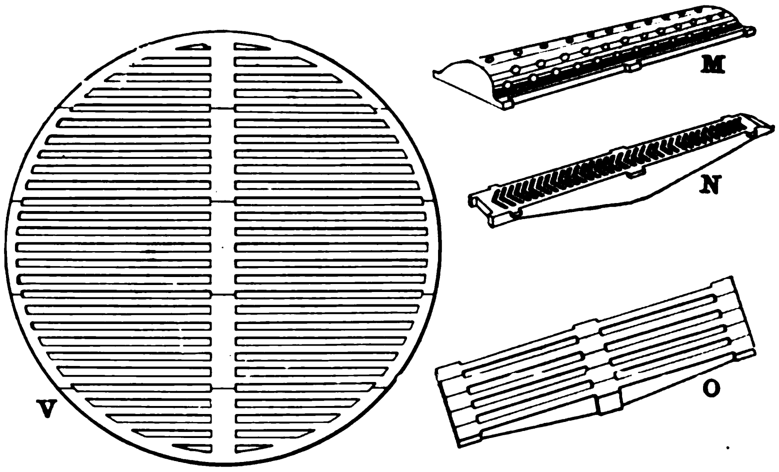


Fig. 1.

fire-box. Fig. 1 shows a few common shapes. The one shown
V is for a circular grate in a vertical boiler, N is called the herrin
bone grate, M, the form used for burning wood and saw-dust, a
O is the ordinary form.

If fine coal is used, the perforations, or air spaces, must be small; the area varying from 30 to 50 per cent. of the total area of the grate. The grate is usually made up of parallel bars and should *never* be made in one solid casting, as it is likely to break from expansion strains. The bars should not be more than three feet long and should be thinner at the bottom than at the top. In order that the spaces may remain the same, even after the top surfaces have become worn, they are made the same thickness for about $\frac{3}{4}$ of an inch from the top. Bars having a section like those shown in Fig. 2 give good results. They are about three inches deep in the middle and have distance pieces at the center as at the ends, to prevent twisting. The air spaces are about $\frac{1}{2}$ inch wide. If the coal is anthracite, which breaks up, the spaces should be as small as the draft will permit; if bituminous, or a coal that cakes considerably, the spaces may be made larger.

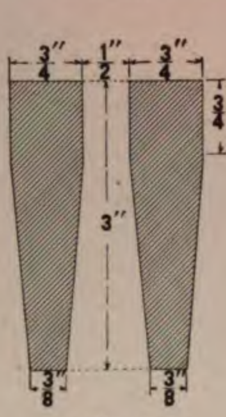


Fig. 2.

In order to facilitate handling, they are often cast in sets of two or more, and when set should be allowed space for expansion at each end, the amount being about one inch in twenty-four. Wrought iron bars are used in locomotives and in boilers where the bars are subject to hard usage. The point of fusion of wrought iron is higher than that of cast iron; but wrought iron bars bend and twist more than bars of cast iron.

Bars are sometimes hollowed and currents of water made to flow through them. By this method their durability is increased and also the efficiency of the furnace. The extra cost, however, and the expense of keeping them in order usually offsets the above advantages.

Rocking Grates. The labor of breaking up clinkers is considerable when ordinary fixed grate bars are used. There are many forms of rocking or shaking grates that do this work without the need of opening the furnace door.

In locomotives rocking grates are necessary, since the rate of combustion is high and the fire must be in good condition at all times. The grate, being below the cab floor, would be very hard to clean if ordinary fixed grate bars were used.

The various rocking grates are operated in many ways; some are flat or rectangular and are moved by shaking backward and forward, others are triangular and are rotated so as to break up the clinkers. The motion is often controlled by cams and levers.

Fig. 3 shows Kelley's standard rocking grate. Each bar is made up of a number of separate leaves, which can be removed and replaced without renewing the whole bar. When the bar is moved back and forth, by means of the lever outside of the brick-work, the leaves rotate through a small angle and grind up the clinkers.

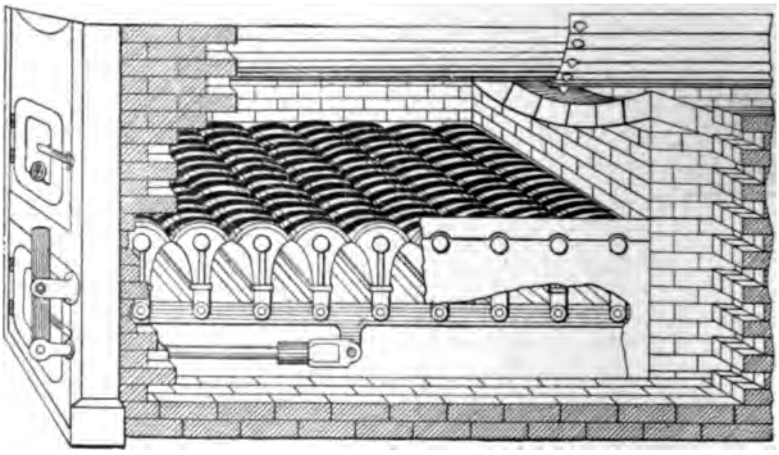
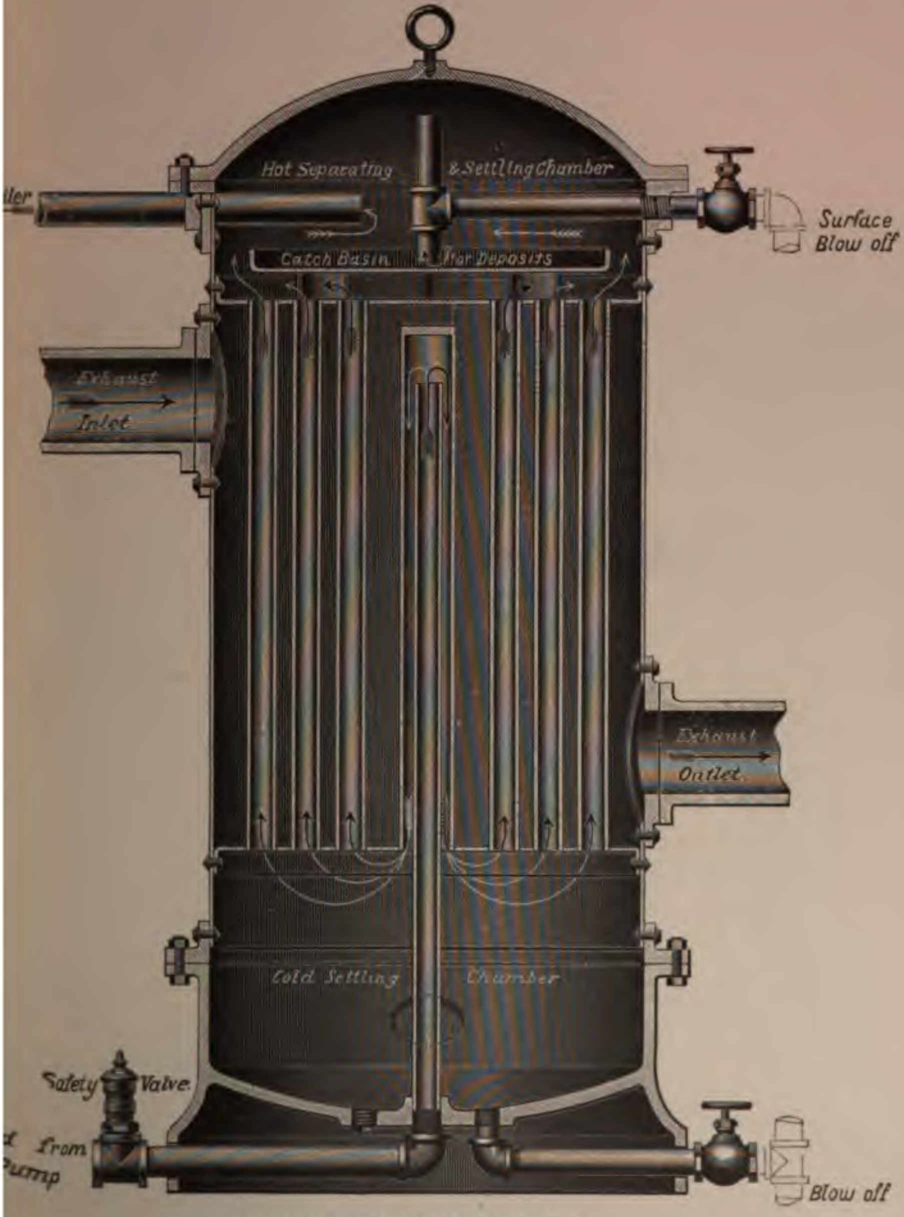


Fig. 3.

Bridge. The bridge is a low wall or partition at the back of the grate. It is usually made of fire-brick, of cast iron, or of ordinary brick covered with fire-brick. It is sometimes of wrought iron, having a hollow space, which is filled with water in communication with the boiler. The bridge guides the hot gases to contact with the heating surfaces and retards their escape. The height depends on the draft. If the space between the bridge and the boiler is narrow, a considerable draft will be necessary to draw the gases through. The best height can be determined only by trial, as it is dependent upon so many conditions. One rule is to make the space about $\frac{1}{6}$ the area of the grate. Hanging bridges



REYNOLD'S FEED WATER HEATER

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are often built behind the furnace bridge, the space between being a combustion chamber.

Two or three bridges are often used to keep the hot gases in contact with the boiler, if it has a long shell.

SMOKE PREVENTION.

In large cities where the escape of considerable quantities of smoke into the air is undesirable, several methods have been devised to prevent the formation of smoke. Among the most important inventions and methods may be mentioned the following: the use of gas fuel, the introduction of jets of steam to thoroughly mix the air and combustible gases, fire brick arches, mechanical stokers, variation of air supply, down draft furnaces and fuel economizers. *The effectiveness* of the above devices depends largely upon the skill with which they are designed and operated.

The actual loss caused by the escape of smoke, even when it is dense and black, has been found to be slight and usually the appliance used for prevention costs more than is saved. The alternate firing of two furnaces, which open into a common combustion chamber, or the alternate firing of two sides of the same furnace produces a slight gain if the proper amount of air is admitted. But, if in order to burn the smoke, the bed in one furnace, or one side of a furnace becomes thin, there will be no gain in efficiency. The introduction of steam is an efficient method, but it is likely to cause a too rapid rate of combustion. Another arrangement to prevent the escape of smoke is that by which the coal is distilled in a small furnace which is separate from the boiler. The coke and gases thus made are burned in the furnace of the steam boiler. This device is not altogether satisfactory on account of the loss of heat from the detached furnace. Rather than add any smoke prevention device, anthracite or coke is used instead of bituminous coal.

Many engineers and business men consider *a good fireman* to be the best smoke preventer.

DOWN DRAFT FURNACES.

In order to increase economy, capacity, or to prevent smoke, a down draft furnace is used. In this furnace there are two grates, one a foot or more above the other. Fresh coal is fed to the upper grate, and as it becomes partially consumed falls through to the grate below where the combustion is completed. The draft is *downward* through the upper grate and *upward* through the lower because the connection to the chimney is from the space between the grates. The volatile gases are carried down through the bed on the upper grate and are burned in the space below it where they meet the hot air drawn upward from the lower grate. A large proportion of the air for combustion enters the door at the upper grate. Tests on the Hawley furnace show that 30 to 45 pounds of coal per square foot per hour can be burned with good results.

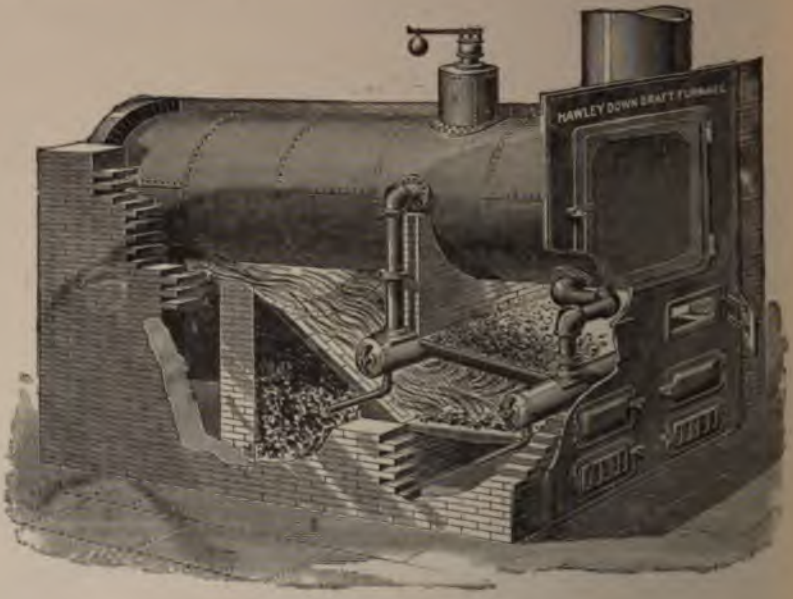


Fig. 4.

In the furnace made by the Hawley Down-Draft Boiler Co., the grates are formed of a series of water tubes, opening at the ends into steel drums, shown in Figs. 4 and 5, which are connected with the boiler. Fig. 4 shows this furnace attached to a

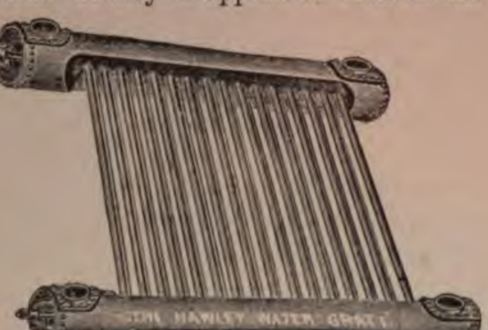


Fig. 5.

horizontal multitubular boiler. It may be applied to both *tubular* and *water tube* boilers with good results and is advantageous to boilers of insufficient heating surface and when inferior fuels are burned. It is claimed that this attachment insures complete combustion, small amount of ashes on account of the second grate, good water circulation and increased economy and capacity.

MECHANICAL STOKERS.

In order to save the labor of feeding furnaces by hand, mechanical stokers are used. With a good mechanical stoker, *one* man can attend several furnaces with little labor. There are several styles. The first was invented by James Watt. The coal after coking was pushed to the back of the furnace by levers.

One form consists of longitudinal bars connected by links forming an endless chain. The coal is delivered from a hopper at the front of the boiler to the grate. The moving of the grate from front to rear moves the coal into the furnace and drops the ash and clinkers at the back.

In the Roney stoker the fuel is dumped into a hopper at the front. The grate bars, which extend across the furnace, form a series of steps. The fuel slides down these steps while it is burning, until it reaches the dumping grate at the bottom. Each grate bar is hung on pivots at the ends. By means of a small steam engine the rocker bar (to which each grate bar is attached), tips the grate bars so that the upper surfaces incline downward toward the bridge, and then rights them. This motion causes the fuel to slide downward and then stop, because checked by the righting of the bars. The rate of feeding is controlled by the stroke of the "pusher," or by changing the number of strokes per minute of the pusher, or rocker bar. The ashes, clinker and the unburned coal, if any, collect on the dumper grate, which is controlled by a lever.

If the rate of feed is too high, unburned coal will appear on the dumping grate. If the rate is too low, no unburned coal will be seen on the dumping grate, and the fire may be thin at the bottom, which will cause an excess of air to enter. The fireman is more likely to be uneconomical by using too little coal than too much, for he can see when unburned coal appears, but does not know the amount of waste caused by a thin fire.

All mechanical stokers in which the movable parts are inside the furnaces, are likely to get out of order because of the heat and dirt.

FUEL ECONOMIZERS.

Of the many attempts to get heat from the products of combustion after they leave the boiler and before they enter the chimney, Green's Economizer, Fig. 6, has been the most successful.

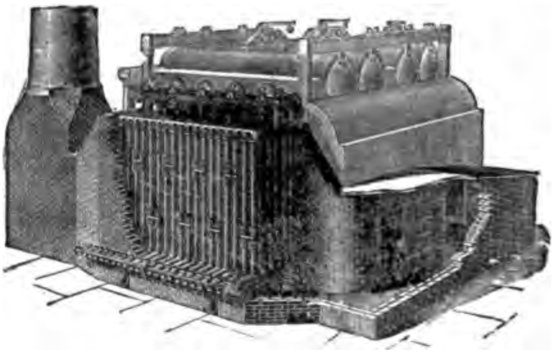


Fig. 6.

Most economizers have been unsatisfactory because of the accumulation of *soot* on the pipes. In Green's feed water heater, or economizer, the several sets of four-inch vertical tubes are kept clean by **scrapers**, one on each tube. By means of a small engine the scrapers move continuously up and down on the tubes. The feed water is pumped through several sets of tubes beginning with the most remote.

SPECIAL FURNACES.

Almost any furnace is adapted to burn anthracite coal, or semi-bituminous coal with less than 20 per cent. volatile matter.

If there is over 20 per cent. volatile matter in the coal, it should never be burned in a furnace that is directly under the boiler whose heating surfaces are exposed to radiation from coal on the grate. If the coal contains over 40 per cent. volatile matter the furnace should be surrounded with fire bricks and have a large combustion chamber.

Some variety of coal is generally used for fuel; but in some localities and industries wood, saw-dust, tan-bark, bagasse and straw are much cheaper or convenient. When these fuels are burned there should be plenty of room in the furnace and sufficient air supplied to the top of the fuel. Saw-dust and fine coal are sometimes burned by blowing them into the furnace by means of an air blast.

When oil is used it is thrown into the furnace by **sprayers** or **atomizers,** the oil burning in a long flame. The sprayer is formed of two concentric conical tubes. Compressed air or steam entering by the inner tube, draws oil through the outer tube and throws it into the furnace in the form of a fine spray. Steam is often used in place of compressed air on account of its convenience, but it is not as good as compressed air. The oil is usually stored in tanks, which are outside the fire room, and which should be lower than the sprayers.

Experiments show that one pound of petroleum is equal in heat units to about 1.8 pounds of coal. Petroleum has many advantages as a boiler fuel. It is clean, gives out uniform heat, and is economical. As there are no ashes to handle and no fires to clean, one man can tend several furnaces. The steady temperature and the freedom from admission of cold air by continual opening of doors increases both the economy and durability of the boiler. The fire may be started or stopped instantly, and the supply of air regulated accurately.

Petroleum has an unpleasant odor, is likely to explode, and has a comparatively high value. Economy from using petroleum or coal depends upon the locality, since prices vary with the difficulty of obtaining them.

NATURAL AND FORCED DRAFTS.

The draft in a chimney is caused by the difference in weight between the hot gases inside and the air outside. The force, or intensity of the draft is equal to the difference of these weights, and is measured by a draft gauge. One form of this instrument is a tube bent in the form of the letter U. The tube is partially filled with water, one leg being connected to the interior of the chimney and the other open to the external air. The difference of the water levels in the two legs indicates the difference of pressures and the amount of draft.

On account of the slight movement of the fluid and the error caused by the water being attracted to the dry tube, the Eames Differential Draft Gage is used. The form is shown by Fig. 7.

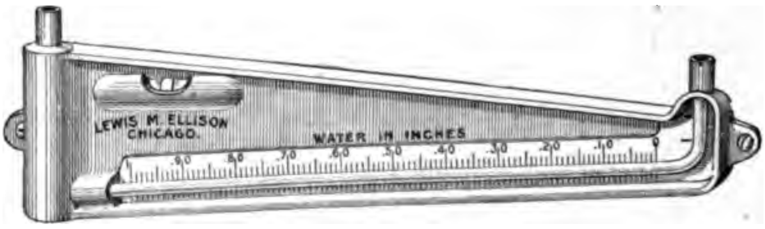


Fig. 7.

The fluid used is a special non-drying and non-evaporating oil of known specific gravity. The incline and diameter of the tube are so proportioned that the reading represents distilled water in hundredths of an inch. The indications are taken on one leg only. The instrument is capable of measuring two inches of water pressure.

The rate of combustion depends upon the height of the chimney. A chimney 20 to 25 feet high will cause draft sufficient to burn about eight pounds of coal per square foot of grate area per hour; if the height is increased, the rate of combustion is increased. If the chimney is about 100 feet high, the rate of combustion will be about 10 pounds per square foot of grate area per hour, and to burn 25 pounds, the chimney must be about 175 feet high. The height of the chimney varies with the fuel and the kind of boiler. For good bituminous, or anthracite coal, the chimney must be higher than for wood or poor bituminous coal, if the same rate of combustion is desired. If the boiler has small or winding passages the chimney must be high. As high chimneys are costly it has become common practice to build two or three small chimneys in place of a large one.

It is often inconvenient and sometimes impossible to build high chimneys or several chimneys when a high rate of combustion is desired. In locomotive and marine work, and in large cities, a high chimney is undesirable. In order to obtain the high rate of combustion with the short stacks of locomotives and ships, a **forced draft** is used. By this means a high rate of combustion is obtained, — from 100 to 150 pounds of coal per square foot of grate area per hour. Forced draft greatly increases the power, but is likely to injure a boiler, and is uneconomical under some conditions.

There are three systems of forced draft. The induced draft used in locomotives, the closed stoke-hole and closed ash-pit used in marine boilers.

Induced Draft. In the first system, the exhaust steam is turned into the smoke stack. The force of the steam draws the products of combustion up the stack. Induced draft is also obtained in land boiler plants by placing a blower in the chimney. An economizer should be used so that the gases may be cooled before they reach the blower. The draft obtained on locomotives is equivalent to a column of water five to seven inches high.

Forced Draft. On steamships forced draft may be obtained either by making the stoke-hole air tight and then forcing air into it, or by increasing the pressure of air in the ash-pit.

By the first method, the stoke-hole is closed so that the only outlet for the air is through the furnaces. Air from without is forced into the stoke-hole until its pressure exceeds that of the atmosphere. This method gives good ventilation to the stoke-hole; but when the fire door is opened there is a great rush of air to the surface of the coal, the cold air chilling the furnace plates. With this form of forced draft the fireman must act quickly.

The closed ash-pit is used successfully both in the merchant service and on war-ships. Air is drawn from without by means of a blower, and is forced into the ash-pit, which has an air tight door. If the pressure is considerable, the fire door must also be air tight, or the flame may come out around the door. When the fire door is opened to admit coal, the draft must be shut off or flame will come out into the fire room. An automatic arrangement, which shuts off the draft when the door is opened, is often used.

The forced draft for marine boilers is usually equivalent to about two inches of water.

Blowers. For ventilation, heating and forced draft, blowers are generally used. In case induced forced draft is desired, a fan or exhauster is placed in the chimney to draw the gases through the passages. With forced draft, either with closed ash-pit or closed stoke-hole, a blower forces air into the ash-pit or stoke-hole.

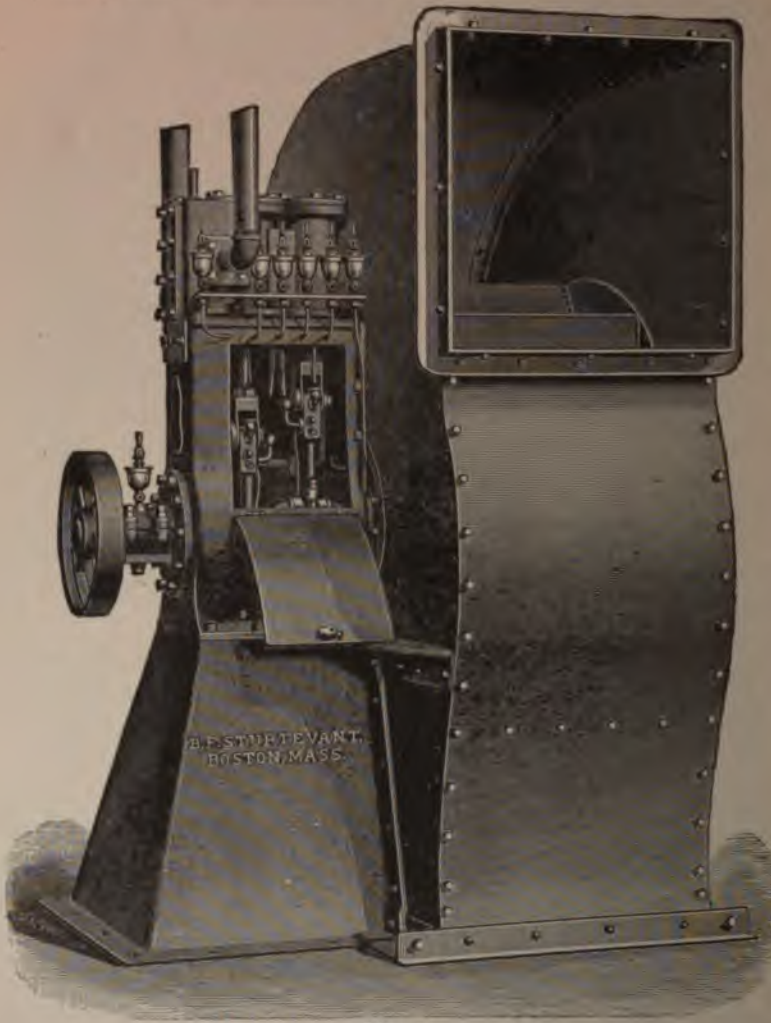


Fig. 8.

Fig. 8 shows a Sturtevant blower with enclosed engines. A blower is a fan wheel encased in sheet iron, brick or wood having two inlets for air. An exhauster is constructed like a blower and has but one inlet. They are made to discharge vertically, horizontally, etc., and are constructed with steel plate fans and designed to handle air, dust, smoke, and steam with low resistances. For forced draft, they are capable of producing air pressure equal to four inches of water, and are very generally used with economizers, and in marine work.

VALVES.

The fittings used to regulate the flow of fluids in pipes are operated by moving a disk across the pipe, with or without rotation, or by turning it through an angle. Those operated by the first method are called valves, and those by the second, cocks.

The Globe Valve, shown in Fig. 9, gets its name from the shape of the case, which is separated into two parts by a partition with an opening through the horizontal part. The fluid enters at the right and passes up through the opening and out at the left. It is closed by screwing down the valve face to the seat by a handle. A stuffing box around the valve prevents leaking. In Fig. 9 the valve is round and is called the disc valve. The valve is guided to the seat by a smaller ring on the valve face. Other forms of globe valves have bevelled seats and the valve face is made of composition. Globe valves should be set so as to close against the flow; when set in the opposite way, if the valve should be detached from the stem it could not be opened, although the handle might move all right. It would also be necessary to shut off

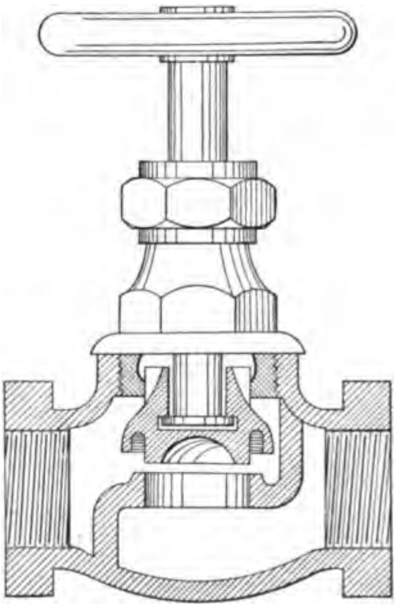


Fig. 9.

the fluid from the entire pipe to pack the valve. This valve offers considerable resistance to flow, since the fluid must make two turns at nearly right angles.

The Angle Valve is sometimes used to take the place of an elbow and stop valve. The inlet is at the bottom and the outlet at the side. The valve is guided to the seat by a rib or ring, the bearing surface being a ring of soft metal. The body of the valve is made of cast iron, the seats, stuffing box, etc., being brass or composition.

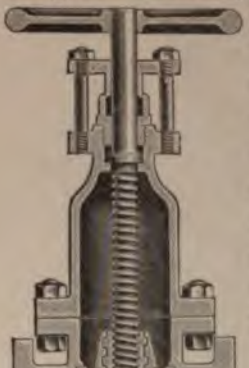


Fig. 10.

The Gate Valve, or straight way valve, gives a straight passage and offers very little resistance to flow when it is open.

There are two forms, one, the wedge shaped valve with wedge-shaped seats and the other having the valve seats parallel. Fig. 10 shows a Chapman valve with wedge-shaped seats. A collar holds the valve spindle at a fixed height. The valve is drawn up or lowered, to open or close, by turning the spindle. When the gate reaches the bottom of the pipe it moves laterally, sufficient to bring a

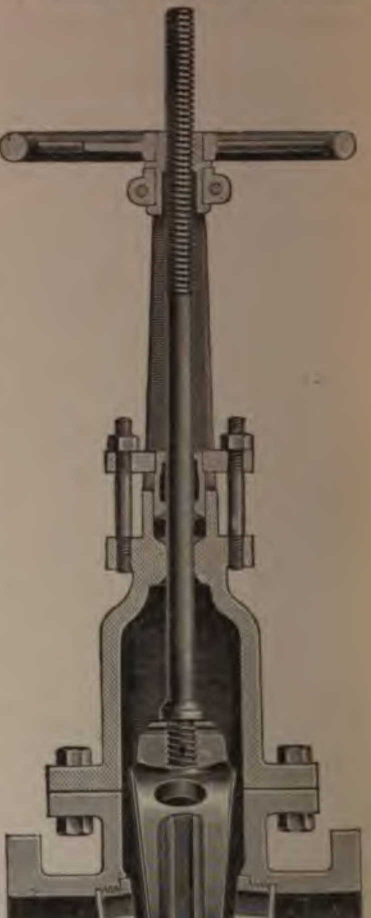


Fig. 11.

strong pressure against the seat. These valves are made with a **stem** which rises with the gate, as shown in Fig. 11, or with one which remains in the same position whether the gate is open or closed. The *former* is preferable as one can tell at a glance whether the gate is open or shut.

Check Valves. When it is necessary that the flow should always take place in the same direction, as in the feed pipe of a boiler, check valves are used. There are several forms shown in Fig. 12, one of which has a similar pattern to a globe valve, with a ball or flat valve, the seat being parallel to the direction of flow. The valve is held in place by its own weight and by the pressure of the fluid, in case of a reverse flow. In the swinging check valve, the seat is at an angle of about 45 degrees to the direction of flow. It is fitted somewhat loosely where it is fastened to the swinging arm, so that it may properly seat itself. This form is usually preferred, as it offers less resistance to flow and there is less chance for impurities to lodge on the valve seat. When a check valve is used in the boiler feed pipe, there should be a *stop valve* between it and the boiler, which can be shut in case the check valve gets out of order.

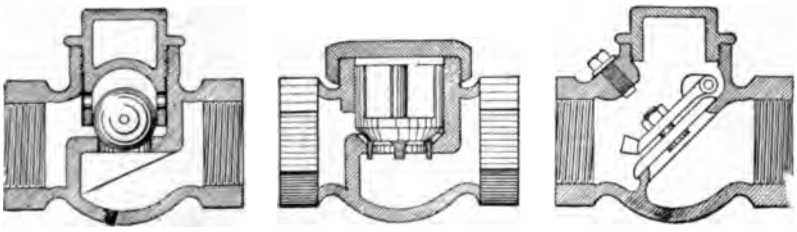


Fig. 12.

SAFETY VALVES.

Safety valves are used for reducing the pressure when it exceeds a certain limit and also to give warning of high pressure. They are constructed in several forms, but in every case they consist of a valve opening outward and held in place by a weight or spring.

A simple form is shown in Fig. 13. It consists of weights suspended from the valve and hanging inside the upper part of the boiler and has a cup-shaped seat. This form is advantageous because the weight cannot be altered without opening the boiler. The *lift*, or the distance the valve rises, is rarely more than $\frac{1}{8}$ of an inch. The area for the escape of steam should be sufficient to discharge all steam that the boiler can make. The area can be computed by an empirical formula proposed by Rankine.

$$A = \frac{70\ W}{p},$$

in which A is the effective area of discharge, W the weight of steam delivered per second, and p the absolute pressure in pounds per square inch.

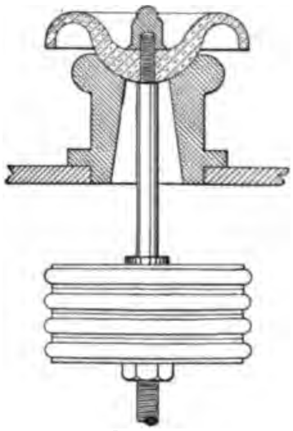


Fig. 13.

The amount of steam depends on the area of grate, rate of combustion and the evaporation per pound of coal. The first condition is known and the other two may be estimated from the prevailing conditions and from the type.

Suppose the boiler makes $1\frac{1}{2}$ pounds of steam per second, with 95 pounds absolute pressure. Then the area will be,

$$A = \frac{70 \times 1\frac{1}{2}}{95} = 1.1+ \text{ square inches.}$$

Suppose the lift to be $\frac{1}{16}$ of an inch, the circumference will be $1.1+ \div .1 = 11$ inches and the diameter will be about $3\frac{1}{2}$ inches.

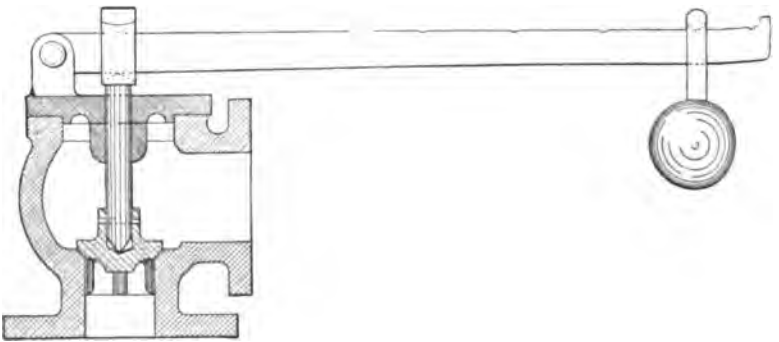


Fig. 14.

Another rule is to make the area of the valve seat $\frac{1}{3}$ of a square inch for every square foot of grate surface.

If more than one method is used in the calculation, the largest sult should be used.

Another form much used is the lever safety valve, shown in ig. 14. The valve is held in place by a weight on the end of a *ver.* The force required to lift the valve is regulated by sliding ie weight on the lever. The body of the valve is cast iron and is an opening at one side to allow the steam to escape. The lve and valve seat are of brass. When the valve becomes leaky, should be reground and made tight, but some carelessly try to op the leak by hanging on extra weight, or by wedging it down. or this reason it is well to have the lever cut off at the proper ngth and to use a short lever and heavy weight.

The method of calculation for the lever safety valve is the me as that for any lever. The safety valve is a lever of the ird class because the power (the steam pressure) is between the lcrum and the weight. In any lever the *weight*, multiplied by e *weight arm*, equals the **power** multiplied by the **power arm.** the lever safety valve the power is the steam pressure, and the wer arm is the distance of the center of the valve from the fulum. There are three weights, since the ball, the lever and the lve and spindle all act downward; their respective arms are the ngth of the lever, the distance of the center of gravity of e lever from the fulcrum, and the distance between the center the valve and the fulcrum.

Thus if we know seven of the following eight conditions, we n find the eighth.

The weight of the ball at the end of the lever.

The length of the lever.

The weight of the lever.

The distance of the center of gravity of the lever from the lcrum.

The weight of the valve and spindle.

The distance of the center of the valve from the fulcrum.

The diameter of the valve.

The distance of the valve from the fulcrum.

Suppose we have a lever safety valve as shown below. We ish to know at what pressure per square inch it will blow. We ow that the product of the total steam pressure on the valve, multiplied by the distance of the valve from the fulcrum, equals the sum of the three weights each multiplied by their respective lever arms, or

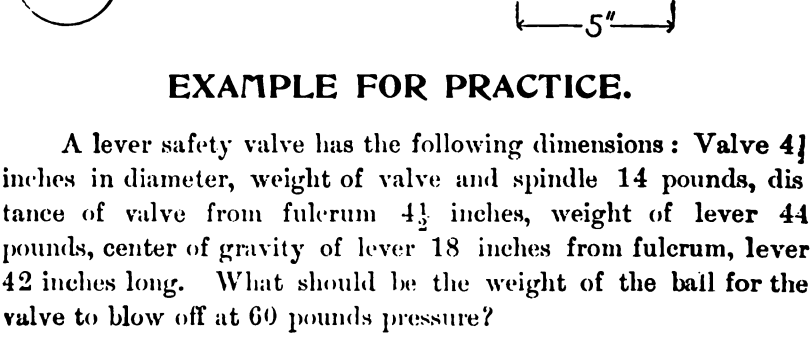
$$
\begin{aligned}
125 \times 48 &= 6000 \\
50 \times 20 &= 1000 \\
18 \times 4\tfrac{1}{2} &= 81 \\
\hline
& \ 7081.
\end{aligned}
$$

$$\text{Area of valve} = \frac{\pi d^2}{4} = \frac{3.1416 \times 25}{4} = 19.635.$$

Let p = steam pressure per square inch; then $19.635\,p$ = the total power. From the law previously stated

$$
\begin{aligned}
19.635\,p \times 4\tfrac{1}{2} &= 7081. \\
88.357\,p &= 7081 \\
p &= \frac{7081}{88.357} \\
&= 80 \text{ pounds.}
\end{aligned}
$$

Then we may say that the safety valve will blow at 80 pounds per square inch.



EXAMPLE FOR PRACTICE.

A lever safety valve has the following dimensions: Valve 4½ inches in diameter, weight of valve and spindle 14 pounds, distance of valve from fulcrum 4½ inches, weight of lever 44 pounds, center of gravity of lever 18 inches from fulcrum, lever 42 inches long. What should be the weight of the ball for the valve to blow off at 60 pounds pressure?

Ans. 82 pounds nearly.

If the pressure at which the valve will blow is known, and the size of the valve is unknown, it may be found by the application of the same principle.

The center of gravity of the lever can be calculated, but a much easier method is to balance it over a knife edge and note the position of the knife edge.

In the above calculations, the theoretical pressure only is calculated. The friction of the various joints may alter the blowing pressure somewhat. A safety valve should be set by trial to blow off at the required pressure. In setting the safety valve a pressure gage should be used that has been compared with a standard gage or mercury column.

The common lever safety valve has several *defects.* It does not close promptly when pressure is reduced; it is likely to leak after it is closed and it can be easily overloaded or wedged on its seat. The safety valve which is automatic, certain in action, prompt in opening and closing at the required pressure, and which can be relied upon to relieve the boiler under all circumstances, is the one desired. The spring, or **"Pop" safety valves** fulfill the above requirements better than those of the lever type. The valves open when the steam pressure is sufficient to overcome the tension of the spring. Fig. 15 shows a Crosby Pop Safety Valve for stationary service. The valve C, the main valve, is connected by the flanged nut B to the central spindle A, and is held down

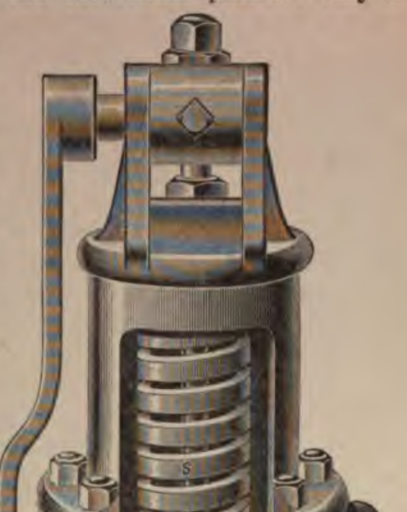
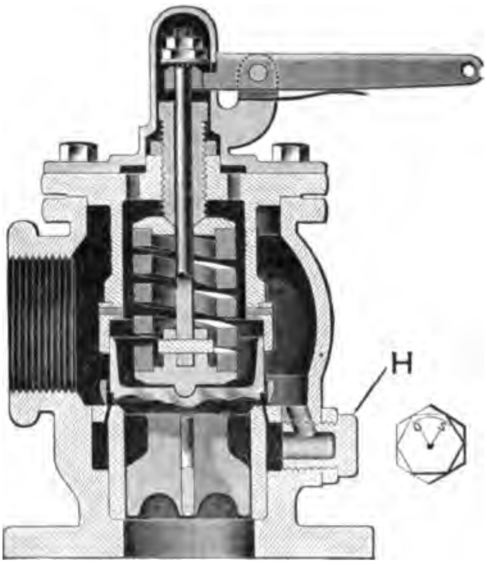


Fig. 15.

on its seat by the pressure of the spring S. The valve C is provided with wing guides and an annular lip E. The guides fit smoothly into the seating D, upon which the valve rests. The seats of the valve have an angle of 45 degrees. The under face of the lip E together with the seating forms a small chamber through which all the steam must pass to the open air. A number of small holes drilled vertically through the flange F, connect with the chamber and allow part of the steam to escape. The action of the valve is regulated by the screw ring G, which allows more or less steam to escape through the holes in the flange F. Raising the screw diminishes, and lowering it increases, the area of the holes. If the loss of steam is too great when the valve blows, turn the screw ring down.

The safety valve should be connected **directly** to the boiler without any pipe or elbow. It should be tried every day by means of the lever.

The valve shown in Fig. 16 for stationary boilers, is made by the Ashton Valve Co. The general principles are those of all pop safety valves. The valve seat is made of composition, or nickle, and with a bevel of 45 degrees, as is the United States Government standard. The pop chamber is surrounded by a knife-edge lip, which wears down in proportion with the seat, thus keeping the outlet of the same relative proportions, giving a constant amount of pop.



Sectional View. Fig. 16.

The amount of pop, that is, the difference of pressure between the opening and the closing of the valve, is regulated from the outside by means of the screw plug pop regulator shown at H in

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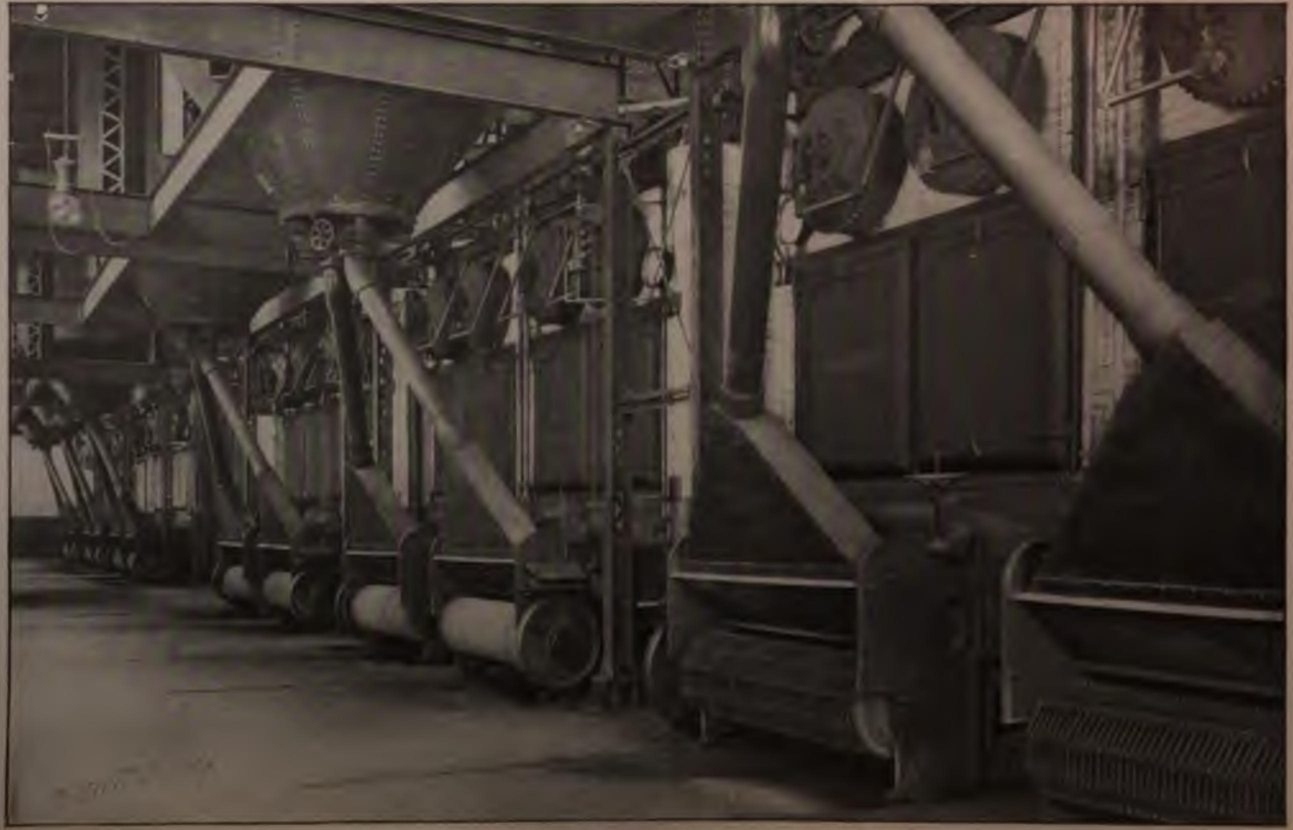


Babcock and Wilcox Boilers with Chain Grate Stokers.

Fig. 16. If more pop is desired, turn the regulator so that S will be more nearly perpendicular. To lessen pop, make O more nearly perpendicular. The springs are made of Jessop's best steel.

The inlet and outlet are both on the same casting, so that the valve may be taken apart to be cleaned or repaired without disturbing the boiler connection. It has a lock-up attachment, so that the regulating parts can not be tampered with, either by accident or design. The spring is encased, thus protecting it from the steam.

The Star Marine Pop Safety Valve is shown in Fig. 17. It has a bevel seat and is provided with a cam lever by which it may be raised from its seat when there is no steam pressure. The outlet of the valve can if desirable, be piped to the supply tank or any other point.

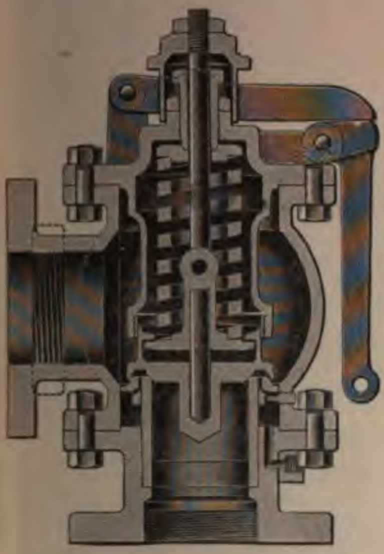


Fig. 17.

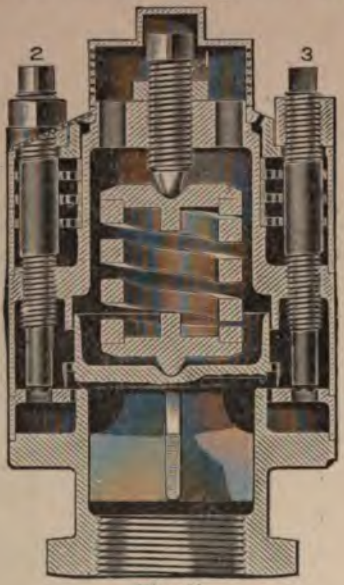


Fig. 18.

The safety valve for *locomotive boilers* must be made of heavy material to stand the severe usage. They should be so constructed that they will not cock or tilt. The Ashton valve shown in Fig. 18 is constructed so that the amount of pop may be regulated by merely turning the two posts marked 2 and 3 to the right or left. The noise of the steam escaping from the ordinary safety valve is disagreeable, and in some states the law requires the use of the muffler safety valve. The Ashton valve shown in Fig. 18 has a top muffler.

REDUCING VALVES.

Sometimes steam is desired at a lower pressure than that of the boiler. For instance, a small low pressure engine may be run by steam taken from the same boiler that supplies a higher pressure engine. This reduction is accomplished by throttling the steam by means of reducing valves. They are arranged to be operated automatically so that the pressure may be reduced and a constant pressure in the steam pipes maintained. There are several forms in general use. Let us consider the action of a few. In the Holt valve, Fig. 19, the low pressure steam acts on the lower side of the diaphragm and the weight, which may be set so as to cause the desired pressure, acts on the other. The movement of this diaphragm causes a balanced valve to move to or from its seat. The valve opens until the steam pressure equals the weight above. The pressure in the

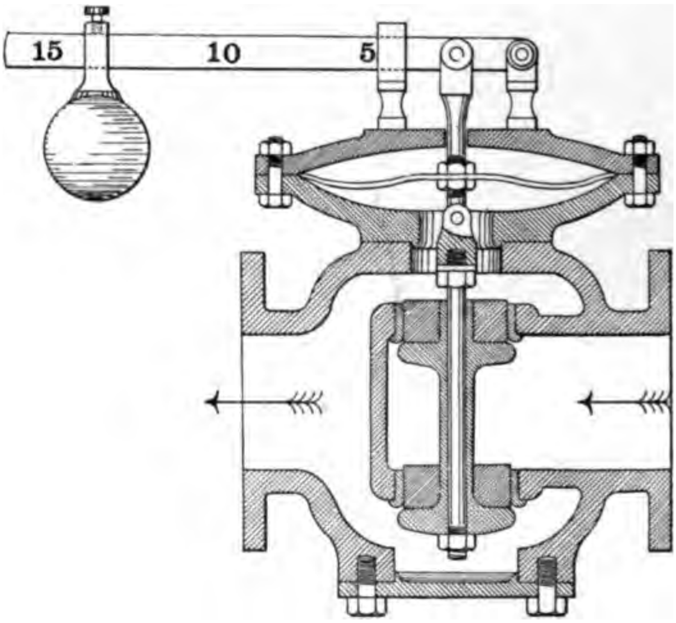


Fig. 19.

nain steam pipe does not effect the movement of the valve. It epends only upon the pressure on the two sides of the diaphragm.

Another form, the Mason, is shown in Fig. 20. A spring, vhich may have its tension altered by key, takes the place of the lever and veight, in the Holt valve. When the ressure in the low pressure system has isen to the required point, which is de-ermined by the spring, the valve closes nd no more steam is admitted until he pressure falls sufficiently to open he valve again.

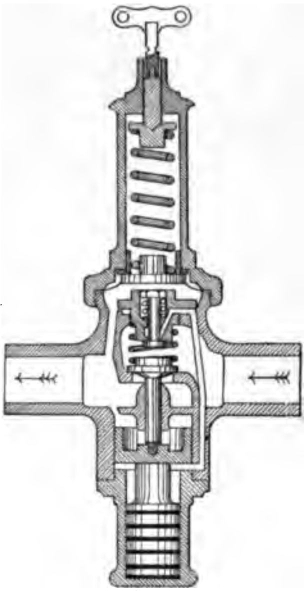


Fig. 20.

In another form, a piston acted on y the low pressure steam regulates the pening of a balanced valve, and this naintains a constant steam pressure.

In the Foster reducing valve, the alve is held open by the spring and evers, until the steam pressure at exit resses on the diaphragm sufficiently to lose the valve. The valve is held open o as to admit just the proper amount of steam to maintain the equired pressure.

When a reducing valve is used, a stop valve should be put n to prevent flow when steam is not in use. It also regulates the upply until it exceeds the leakage of the reducing valve.

BLOW-OUT APPARATUS.

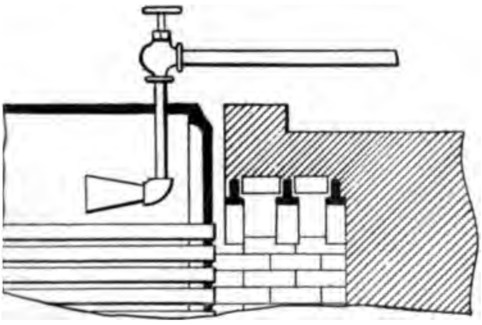


Fig. 21.

Water for feeding boilers, if taken from rivers or ponds, is likely to contain some vegetable matter. As this matter usually floats on the surface of the water in the boiler, it may be discharged through a **surface blow-out**. This pparatus, shown in Fig. 21, consists of a flattened cone of sheet metal extending nearly across the boiler and turned so that the currents will deposit solid matter in its mouth. The valve is opened frequently to blow out these vegetable impurities.

There are many solid impurities that will settle to the *bottom* of a boiler if the water is allowed to remain quiet for a short time. By means of a mud drum, or a **bottom blow-out apparatus**, these solid particles are removed. In many boilers, the blow-out cocks are kept open every morning long enough to reduce the level of water in the boiler a few inches. This blow-out apparatus is situated near the bottom of the boiler, in order that it may be completely drained. *Valves* are more easily opened than *taps*, but are not as trustworthy. It is almost impossible to completely close a valve if a small piece of scale, a small chip, or an accumulation of sediment lodges on the seat. If the valve is not closed tightly, water will leak out; the boiler may be drained, and then become overheated. One is not deceived as to whether a tap is closed or open. For these reasons it is better adapted for blow-out apparatus than a valve. A tap is likely to stick fast because of corrosion, or unequal expansion, but this difficulty is slight if it is opened *frequently* and *gradually*. The plug and casing should not be made of the same metal, because they will stick if they remain in contact for any length of time.

WATER GAGES.

It is of great importance that the level of the water in the boiler can be easily ascertained at any time. If the water is too **low** there is danger of **over-heating** the furnace plates; if it is too **high** there is likely to be **priming**.

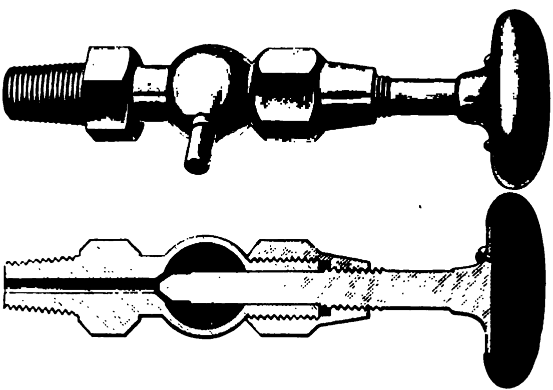


Fig. 22.

The water level is usually indicated by gage cocks, water gage glasses and floats.

Gage cocks, or **Try cocks**, are very generally used. They are of different forms, varying with the makers. Fig. 22 shows a form for locomotives. It is so constructed that it can be separated for the purpose of repacking the working parts without detachment from the boiler. The one shown in Fig. 23, used largely on stationary boilers, is made both with and without packing.

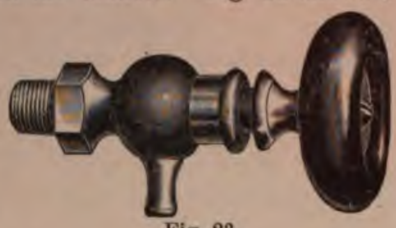


Fig. 23.

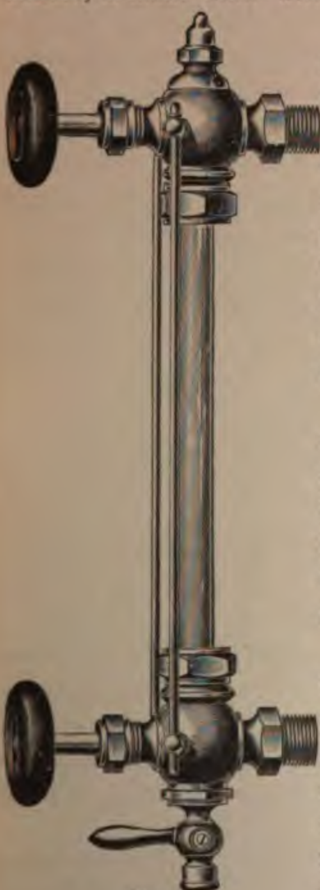


Fig. 24.

There are usually three cocks, one placed at the highest position that it is desired to have the water level, one placed at the lowest position and the other halfway between. For greater accuracy more cocks may be used. The position of the water level is determined by trying the cocks. If steam escapes from the highest one, and water from the next, the water level is evidently between the two.

In flat ended, multitubular, flue and marine boilers the cocks are usually placed on the *front* end. If the boiler is encased in brickwork above the water level, the water level is found by connecting the cocks with the boiler by means of small pipes.

Gage Glasses. In order that the fireman may know the water level *without* trying the cocks, a water gage glass is used. It consists of a strong glass tube about one foot in length having the ends connected to the boiler by suitable fittings. As both ends of the tube are in communication with the boiler, the water level in the glass will be the same as that in the boiler, and is **always in sight**. Fig. 24 shows a good form of gage glass. The glass is protected by rods which are parallel to it. As the glass frequently needs cleaning, repacking, or renewing, cocks are provided for shutting off communication with the boiler. A drain cock also is placed at the lower end to empty the glass when the attendant wishes to ascertain whether the glass is working properly or not. The drain cock is often provided with a drain pipe. The steam and water passages should be at least one half-inch in internal diameter.

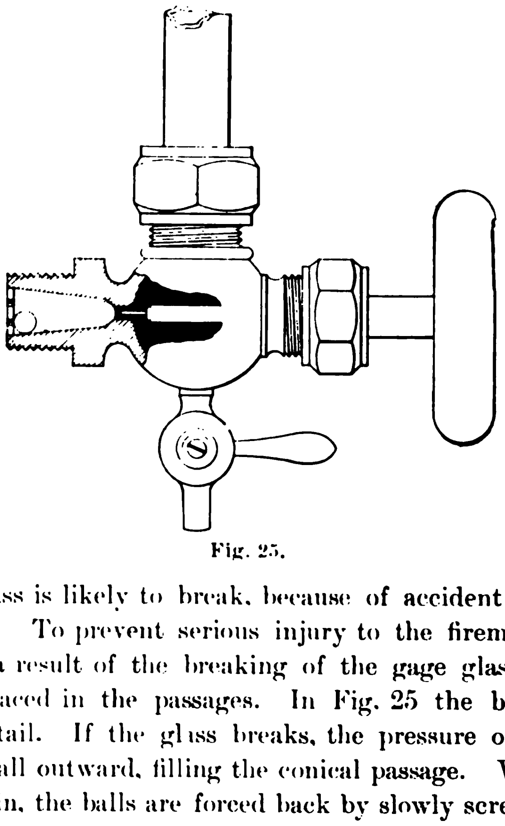


Fig. 25.

The glass is likely to break, because of accident or unequal temperature. To prevent serious injury to the fireman and loss of water as a result of the breaking of the gage glass, *automatic valves* are placed in the passages. In Fig. 25 the ball valve is shown in detail. If the glass breaks, the pressure of the steam drives the ball outward, filling the conical passage. When a new glass is put in, the balls are forced back by slowly screwing in the stems. This, like other safety devices, is very likely not to work when it should.

In boilers where the steam space is small, as in locomotives, the allowable variation of water level is slight, but the greater care with which the glass is watched makes up for the small margin of safety. If dirty water is used, or if the water foams, the level in the glass will be unsteady and unreliable, since dirt clogs the passages, unless they are large, and the foaming causes a fluctuation of the water level. A small pipe connecting with the steam space where no ebullition occurs will insure a steadier water level. If the steam and water connections are long, they should be made large.

Two water gages should be used on every boiler, one as a check on the other, and also for use if one breaks. They should be placed at the furnace end of the boiler in order that they may be easily seen.

There are numerous arrangements for indicating the water level by means of floats. The most common is the counterbalance and pulley. Sometimes a whistle is attached to the float which gives warning when the water level becomes dangerously low. In using a float, the wire should never be made of iron, as it is liable to corrode, nor should it be large as it is more difficult to pack and more likely to be bent permanently. When carefully made and attended, floats are reliable water indicators. There should always be two, one at each end of the boiler.

STEAM AND VACUUM GAGES.

The steam pressure in the boiler is measured in **pounds per square inch.** When we say the boiler is working or steaming at 80 pounds pressure, we mean that the gage pressure is 80 pounds, that is, the pressure in the boiler is 80 pounds above **atmospheric pressure.** It could be measured by a water or mercury column, but as they would need to be very high to measure the pressures used at the present day, they are not practicable. A spring pressure gage is used instead.

Although not absolutely necessary for safety, it is very desirable that every boiler have a reliable steam gage to indicate the steam pressure.

The dial gage, now used almost universally, was invented by M. Bourdon. It is designed with reference to the principle that a flattened, curved tube closed at one end, tends to become straight when subjected to internal pressure.

The tube, which is usually oval in section, is bent into the arc of a circle as shown in Fig 26. One end is *fixed* and is in

The pipe which connects the pressure gage to the boiler should have bends in it near the gage. These bends, or better a **coil pipe** as shown in Fig. 30, are filled with water which transmits pressure and keeps the spring at a nearly constant low temperature. Gages

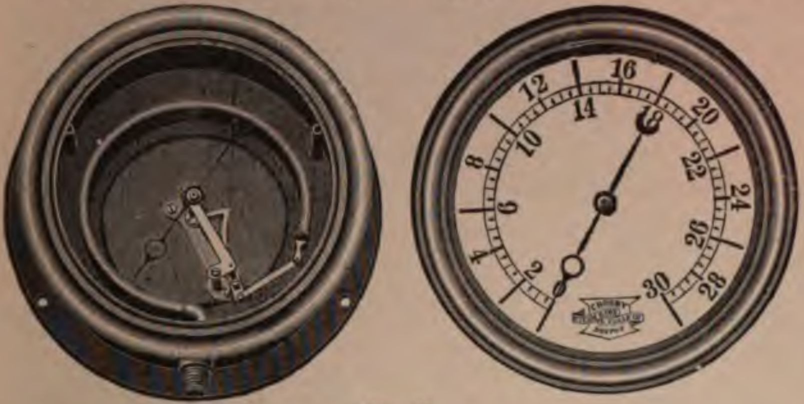


Fig. 28.

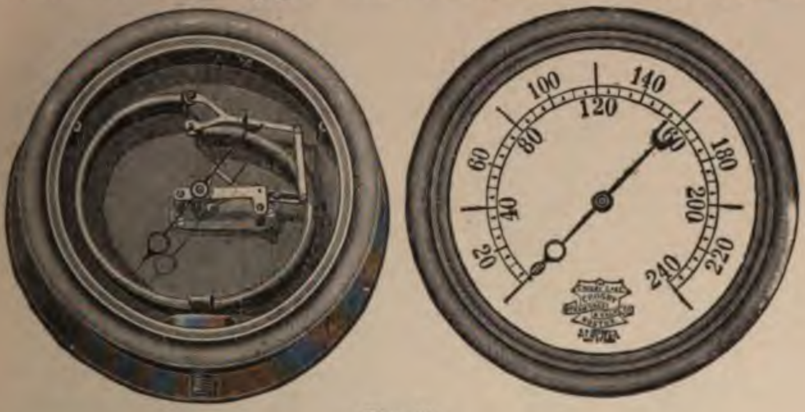


Fig. 29.

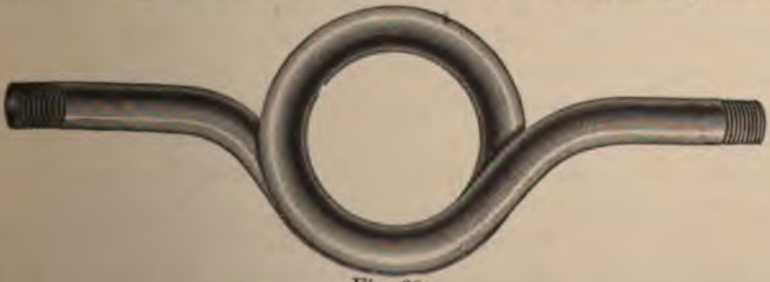


Fig. 30.

should be placed where the water in the coiled pipe will not freeze; also, the gage should not be exposed to strong heat. In order that the gage may be removed from the boiler, for examination, repairs, or calibration, when the boiler is under pressure, the connection should be provided with stop cocks.

In a battery of boilers, **each** should have its pressure gage. It should be connected **directly** to the boiler, **not** to the steam pipe.

FUSIBLE PLUGS.

Fusible plugs are frequently inserted in the plates of boilers as a safeguard against collapse of the furnace crown. They consist of a core of an alloy of tin, lead and bismuth, and a covering of brass or cast iron. While the alloy is kept at a comparatively low temperature by the water on one side, the fire on the other will not melt it. But when the water level becomes low enough to leave the plug uncovered, the core of alloy, having a low melting point, is expected to fuse, thus relieving the pressure in the boiler and extinguishing the fire. Fusible plugs are unreliable; blowing out when there is no apparent cause, and sometimes remaining intact when the plates become overheated. If a coating of hard scale is allowed to form over the fusible plug, it may stand considerable pressure even after the alloy has become melted. The nature of the fusible alloy may change if it is exposed to heat for a considerable time.

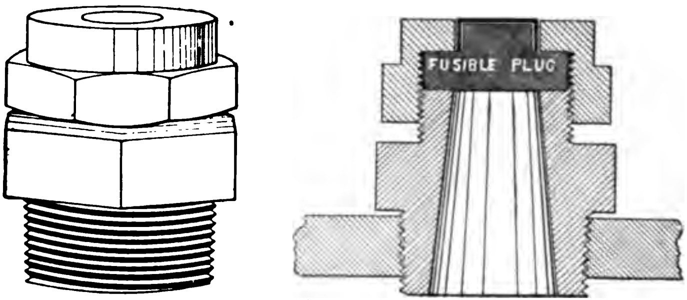


Fig. 31.

Fusible plugs should be cleaned from soot and dirt and the surface scraped frequently. They should be renewed every three or four months that no change may take place in the nature of the alloy. The fusible plug should be made of such shape that when screwed into the crown-sheet it projects one and a half or two inches *above* the plates, so that when the alloy melts there will still be sufficient depth of water over the exposed plates to prevent injury from heat. The core is often made annular with a copper center. This gives a very large opening. Sometimes the core is covered with a thin copper cap, shown in Fig. 31, which protects the alloy from contact with the water, thus preventing chemical change and the formation of scale. Fig. 32 represents a fusible plug in the crown sheet of a fire-box boiler.

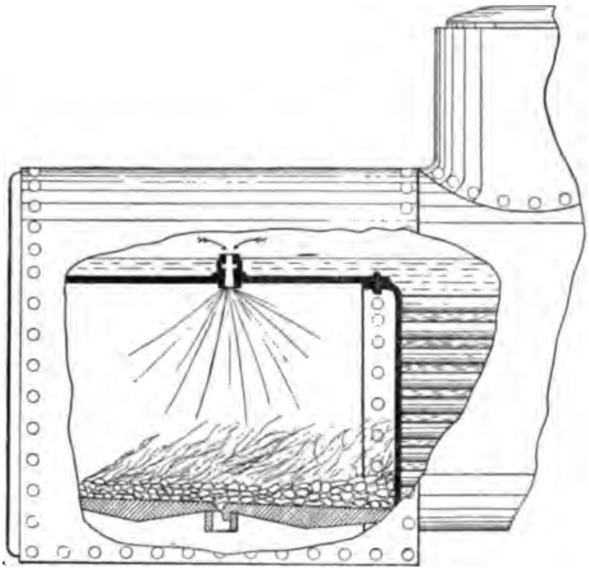


Fig. 32.

Fusible plugs are placed in the plates which are directly exposed to great heat. The following are some of the places where a fusible plug is used:

In the crown sheet of a locomotive fire box.

In the lower tube sheet, or a little above the crown sheet, in one of the tubes of a vertical boiler.

In the back head of a cylindrical tubular boiler, about three inches above the top row of tubes.

In the lower portion of the upper drum of a water tube ooiler.

It does not necessarily follow that a hole one half or three fourths inch in diameter will liberate steam fast enough to prevent excess of pressure. If a small quantity of steam is introduced into the fire box, the fire may brighten and the heat of combustion be greatly increased, because the steam will have an effect similar to that of forced draft. If, however, the quantity of escaping steam and water is considerable, combustion will be retarded and pressure relieved.

STEAM SEPARATORS.

The water surface of a boiler may not be sufficient for the *free disengagement* of steam, and so cause ***wet steam.*** Some water-tube boilers are defective for this reason. If steam is carried for some distance in a pipe, some of it will be condensed, and the water accumulating in a joint or sag in the pipe, is carried over to the engine when the pressure in the pipe increases slightly. This is likely to cause ***injury*** to the engine, besides being ***uneconomical.*** The amount of water thus formed in the pipe is greatly reduced by **superheating** the steam. If it is undesirable or inconvenient to superheat the steam, there are several ways to remove the water of condensation. One method is to let the steam come to rest in a drum of considerable size; the water is drained from the drum and the steam flows from the top by a pipe. If the drum is small the steam may not come to rest and the water will not separate from the steam.

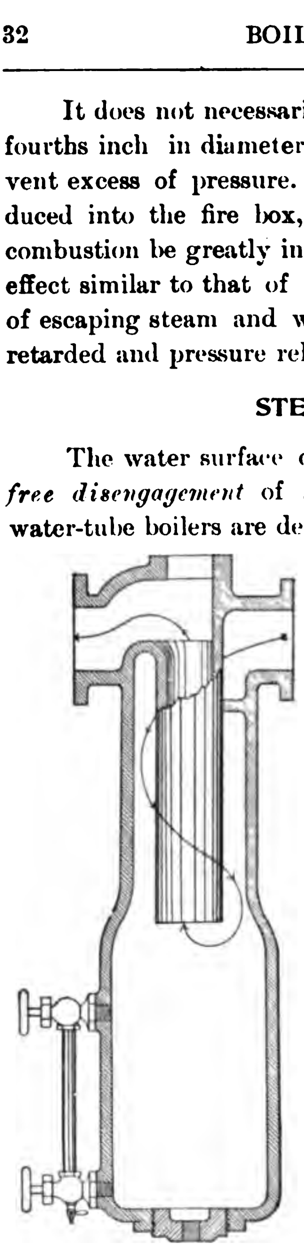
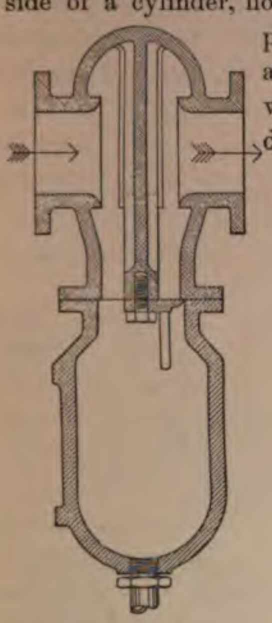


Fig. 33.

Another method is the use of a steam **separator.** There are several forms which are designed from the principle that if the direction of a current is suddenly changed, or if it goes downward then upward the water will separate from the steam and fall to the bottom.

In the Stratton separator, Fig. 33, the steam enters at one side of a cylinder, flows downward and then upward through a pipe in the middle. Dry steam escapes from a pipe near the top on the opposite side from which it enters. The separated water is drained at the bottom.



The Cochrane steam separator, shown in section in Fig. 34, is of the baffle plate type. The branches for the entrance and exit of the steam project from each side of the spherical head. Another branch from the bottom provides for connection with the well. The baffle plate, which is cast as a part of the head, is ribbed, or corrugated, and has ports at each side for the passage of steam. The area of the ports is large to prevent loss by friction. A small pipe is inserted in the lower plate of the outlet side of the baffle plate to drain any condensation in the outlet chamber. Steam entering at the left hand opening strikes the baffle plate and passes to the outlet chamber by means of the two side passages, as shown in the plan of Fig. 34.

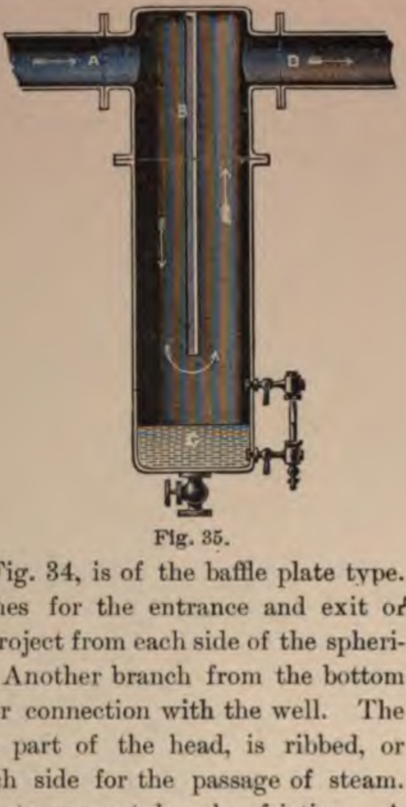


Fig. 35.

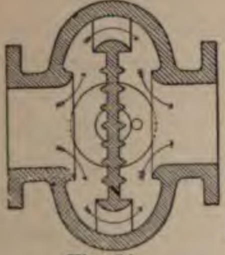


Fig. 34.

A form of separator which is fitted to the main steam pipe near the engine is shown in Fig. 35. Steam enters at A and strikes the dash plate B; any water coming with the steam is separated and falls to the bottom. The steam takes the direction indicated by the arrows and flows out at D. This separator is fitted with a gage glass which is similar to a boiler gage glass.

STEAM TRAPS.

Steam traps are used to drain water from steam pipes. Traps usually consist of a vessel, or receptacle, into which water drains. The exit is a valve controlled by a float, which arrangement allows water but not steam, to pass.

In the **float** trap shown in Fig. 36 the float rises and falls with the change in the level of the water. When the water level rises above a certain point, the float opens the discharge valve. The trap shown in Fig. 37 is similar, the float being replaced by a weight W which is nearly counterbalanced by the weight T. The rising of W opens the valve V.

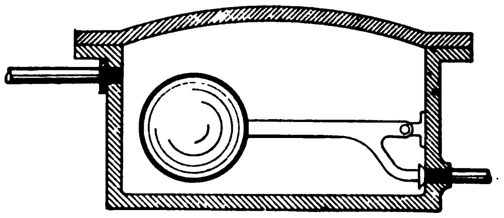


Fig. 36.

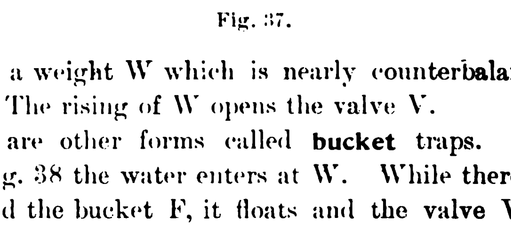


Fig. 37.

There are other forms called **bucket** traps. In the one shown in Fig. 38 the water enters at W. While there is a little water around the bucket F, it floats and the valve V is closed, but when the water rises high enough to flow over the edge, the weight of water in the bucket causes it to sink and opens the valve V. Water is forced up the passage M and out the pipe N

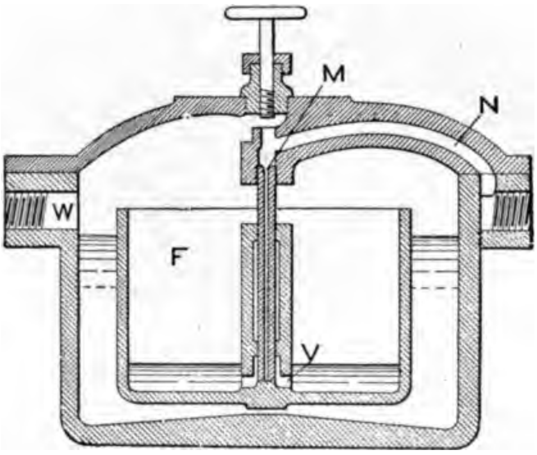


Fig. 38.

by the pressure of the steam on the surface of the water which surrounds the bucket.

Another form of trap called the differential steam trap depends upon a head of water acting on a flexible diaphragm. Water enters at either top or bottom by the pipes E, Fig. 39. When the water level rises it fills the chamber G and the pipe N. This causes a pressure on the under side of the diaphragm greater than that caused by the spring H, which acts on the upper side of the diaphragm and tends to open the valve. When the water rises and fills the chamber J so as to flow down the pipe M, the water-pressure on the upper and lower side of the diaphragm will be equal because the head of water in M is practically the same as

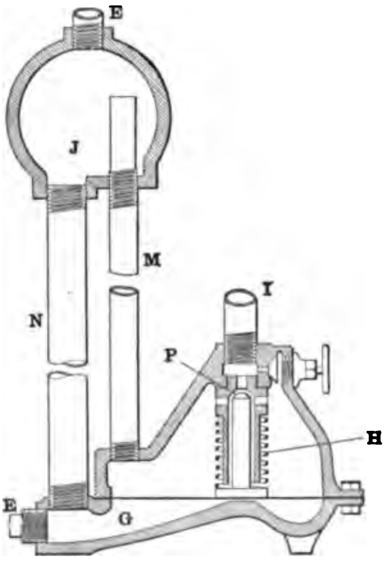


Fig. 39.

that in N. Then the spring will open the valve P and water will be discharged from the pipe I. When the head in M falls, the pressure on the under side of the diaphragm becomes greater and the valve closes.

Return Traps. Traps that are used for returning water of condensation to the boiler are called **return traps**. There is a variety of form, but the principle of action is similar and is shown in Fig. 40. B represents the boiler and T the trap, which is placed a few feet above the boiler. The trap is supplied with steam from the boiler. It is also connected with the boiler by the pipe P in which is a check valve at C. Water of condensation enters the trap through the pipe E, in which is a check valve H, until it reaches a depth sufficient to raise the float F, which opens the balanced steam valve V, called an equalizing valve. Steam from the boiler then enters the trap and equalizes the pressure. Since the pressures are equal, water in the trap, because of its height above the water level of the boiler, will flow to the boiler until the level in the pipe P is nearly the same as the water level of the boiler. As the water level in the trap falls, the float F drops and the equalizing valve is closed. In other forms buckets are used instead of floats.

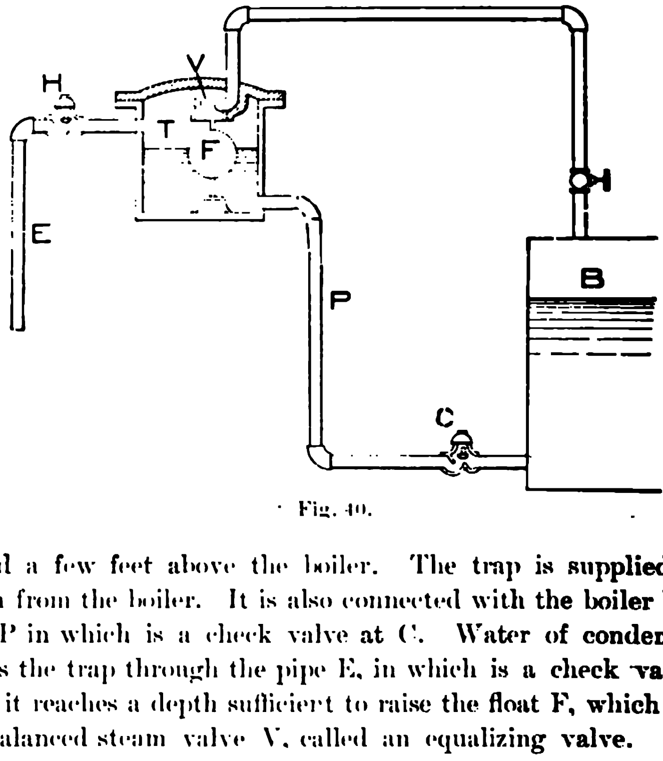
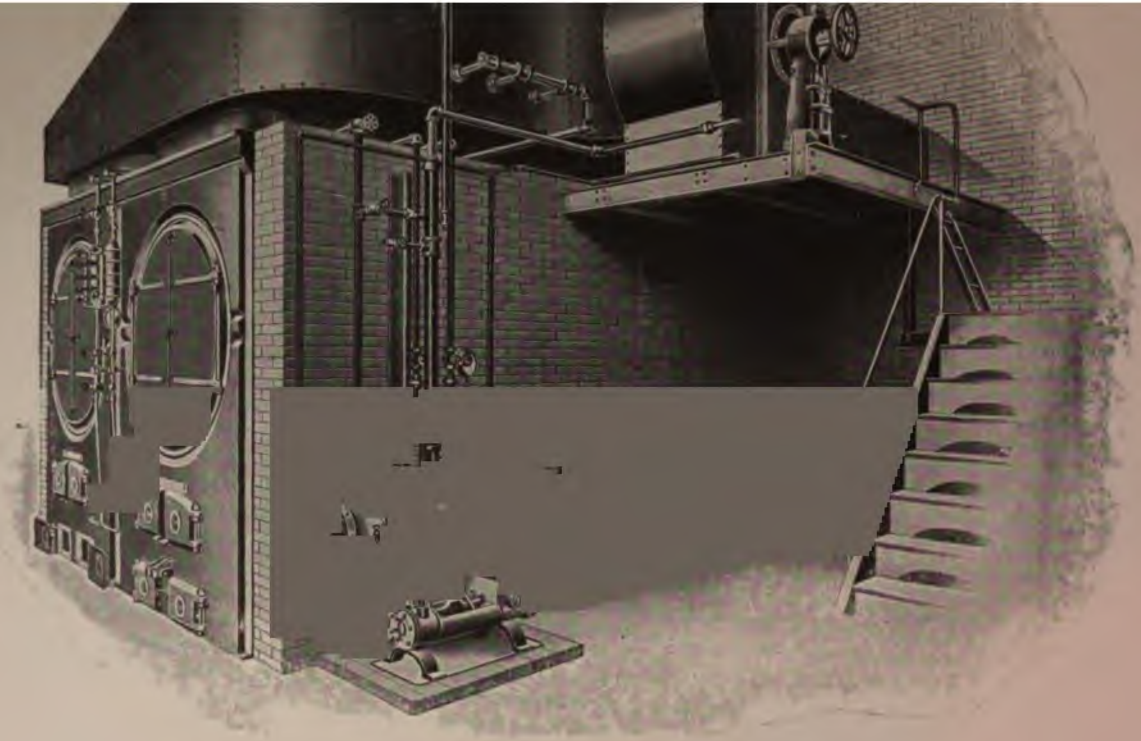


Fig. 40.

Steam Domes. Steam domes or chambers are attached to



STEAM FAN FOR INDUCED DRAFT
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boilers for the purpose of obtaining dry steam and as a remedy for priming. They are supposed to be reservoirs to store a supply of steam, that may meet any sudden demand. The cutting away of a large piece of plate weakens the boiler considerably. Domes, if used, should be as small as convenient and the boiler plates around the hole should be strengthened as for manholes.

SUPPORTS.

There are two common methods of supporting boilers; *1.* By means of brackets; *2.* By suspending from wrought iron beams.

If the boiler is about 15 feet long, it is customary to use two brackets on each side. If more than 15 feet, three on each side are used. The front brackets rest on the brickwork, but the others rest on small iron rollers to allow for expansion. Brackets are so arranged that the plane of support will be a little above the middle. There are several forms of brackets. The form shown in Fig. 41 is usually made of cast iron and is provided with rivets above the flange of the bracket. It is better to have the rivets both above and below the flange as shown in Fig. 42.

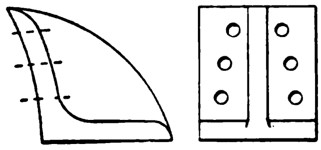


Fig. 41.

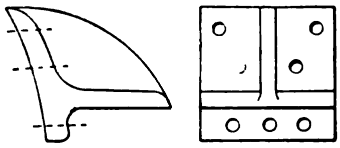


Fig. 42.

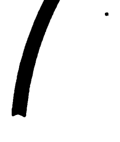


Fig. 43.

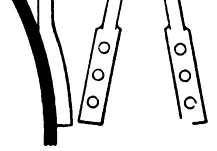


Fig. 44.

Fig. 43 shows the method of suspending from beams. The lug, made of wrought iron, is riveted to the plates of the boiler. A bolt having one end bent like a hook holds the lug from the beam. In Fig. 44 the lug is replaced by a loop of wrought iron. Fig. 45 shows another method of suspension; the connection between the rod and boiler plates being short pieces of boiler plate arranged for flexibility.

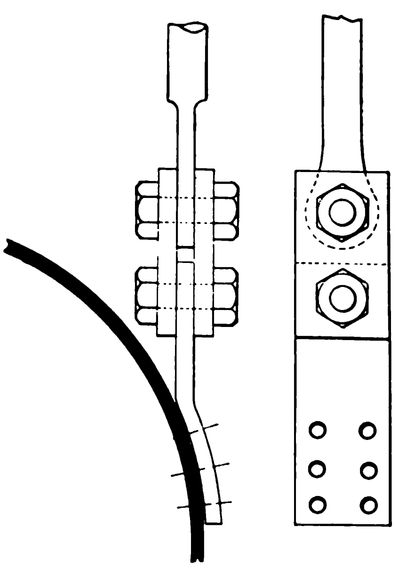


Fig. 45.

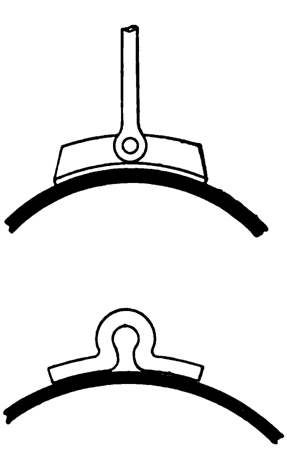


Fig. 46.

When the boiler is of small diameter, it may be suspended as shown in Fig. 46.

MANHOLES AND HANDHOLES.

A manhole allows access to the boiler for cleaning and repairs. It is usually elliptical in form and large enough to admit a man. About 16 inches for the major axis and 12 for the minor axis is a good size. The manhole is closed by a plate or cover made of cast or wrought iron. This plate is held to the seat by a yoke or yokes, and bolts. Fig. 47 shows one form, Y being the yoke, L the cover and N the bolt. The joint between the cover and the shell is made steam tight by packing.

The **strength** of the manhole is important. Wherever a large hole is cut in the plate the edge should be strengthened, for the tension is concentrated there and the plates are, moreover, likely to become weak by corrosion. The *strain* put upon the plate by screwing up the cover is considerable, especially if a piece of scale gets between the faces, and the joint is then made tight.

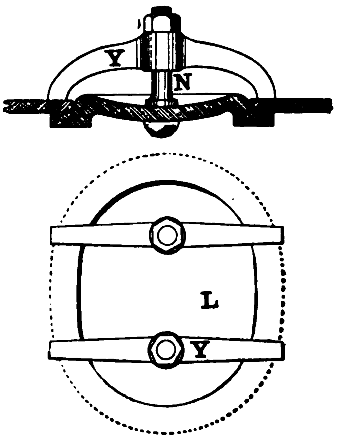


Fig. 47.

Fig. 48 shows the section of a strong and simple manhole. The edge of the plate is strengthened by a broad ring of steel. The ring is flanged and riveted to the shell, its edge forming the seat. The cover as shown in the figure is shaped for strength. The edge of the ring which forms the seat and the cover are machined to make a tight joint without packing. The strengthening ring should be at least $\frac{5}{8}$ of an inch thick and 4 inches wide, that the rivet holes may not be too near the edge. The rivets should have a pitch of about 3 inches.

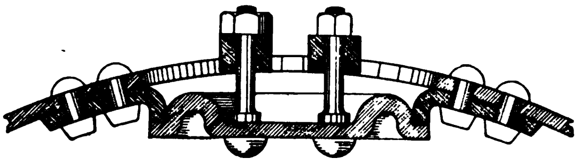


Fig. 48.

Handholes and **mudholes** are more commonly placed in boilers, which are so constructed that a man cannot enter; in a vertical boiler for example. They are used to some extent in other boilers; in horizontal return tube boilers there is usually a handhole in each end near the bottom. Handholes are very convenient to admit hose for washing out the boiler, also for removing scale and sediment. Handholes are similar to manholes in construction, but require only one yoke and one bolt to keep them in place. Mudholes should be provided in order that the sediment and detached scale may be removed without lifting it to the top manhole. Mudholes and handholes greatly facilitate cleaning the fire-box water leg of locomotive and small vertical boilers.

FEED APPARATUS.

There is a great difference of opinion as to where the feed water should be introduced into a boiler; although in common practice it is admitted at the rear, near the bottom. The best place depends upon the arrangement of the heating surfaces. Whatever may be the saving by introducing it at some particular point, there are practical considerations that must not be overlooked. If the entering water is of high temperature, it makes less difference where it is introduced.

In externally fired boilers, the feed pipe is sometimes introduced at the top and extended downward to within a few inches of the bottom. If the water is cold and the plates near which it is delivered are hot, this practice is dangerous, as the sudden chilling of the hot plates causes leaking, rupture, etc. If the pipe is cut off so that there is about two feet between the bottom of the boiler and the end of the pipe, the injurious effects are diminished. Another plan is to fix a vessel under the end of the feed pipe. Water is better distributed as it flows over the top of the vessel, which may also be used as a mud drum or sediment collector. It is a good plan to admit the feed water by a horizontal pipe, entered at either tube plate a few inches below the low water level, and terminated in a trough or a perforated pipe of large diameter. This method distributes the water and allows it to become warmed before it reaches the bottom.

In internally fired boilers of the Cornish and Lancashire type, the feed is usually delivered near the bottom by a horizontal pipe through the front end plate, or by a vertical pipe through the crown. If the feed water is admitted near the bottom, it has a tendency to remain there and increase the amount of dead water that remains cold because of poor circulation.

By introducing it at a high point the circulation is improved since the cold water, being heavier, descends. Temperatures also are equalized by the heating of the water during its fall. There is another reason why it is advisable to introduce the feed water a few inches below the low water level. If a chip or piece of scale lodges on the seat of the check valve and it fails to work, the boiler may be drained should the feed pipe enter near the bottom.

By making the internal feed pipe of considerable length, the water is warmed before it mixes with the hot water in the boiler.

In internally fired vertical boilers, the feed pipe is short and enters just below the water level.

With feed water containing a large per cent. of bi-carbonate of lime, the feed pipe should terminate in a trough, or a pipe of large diameter with the upper side cut away. If a perforated pipe is used, the small holes are likely to be clogged by the rapid precipitation of lime.

The feed supply should always be regulated to keep the water level as nearly stationary as possible. It is more economical and far better for the boiler, than to wait for the water level to fall and then feed a few inches rapidly. The sudden introduction of a large volume of water causes contraction of the plates, leakage and necessitates rapid firing.

The introduction of feed water at a high temperature increases the economy and tends to prolong the life of the boiler. The increase in economy may be shown by a few figures.

Suppose the steam pressure in a certain boiler is 100 pounds by the gage and the feed water enters at 60° F. What will be the per cent gain if the feed is heated to 210° F.?

The number of heat units required to convert a pound of water at a given temperature, into steam at a given pressure, is equal to the difference in the total heat of the water and steam. From the definition of B. T. U. we see that the total heat in one pound of water at 60° F. is equal to $60 - 32 = 28$ B. T. U.; 32° being the freezing point. The total heat in one pound of steam at 115 pounds absolute pressure is 1,185 (see 3d column of steam tables, page 110.) The difference between these two total heats is $1{,}185 - 28 = 1{,}157$ B. T. U.

In using the steam tables always convert gage pressure into absolute pressure by adding 15 pounds. Hence, the absolute pressure of 100 pounds (gage) is 115 pounds.

If the water is heated from 60° F. to 210° F., the number of B. T. U. gained by heating is $210 - 60 = 150$. The gain in per cent would be,

$$\tfrac{150}{1157} = .13 \text{ (nearly) or 13 per cent.}$$

The injurious effects from unequal expansion are diminished, and when the feed is warmed by exhaust steam or the waste gases, the saving of fuel is considerable.

There are several ways of heating the feed water. In condensing engines, the hot water from the hot well is used; the temperature in the well being from 100° to 140° F. With a non-condensing engine, the feed water may be heated by the exhaust

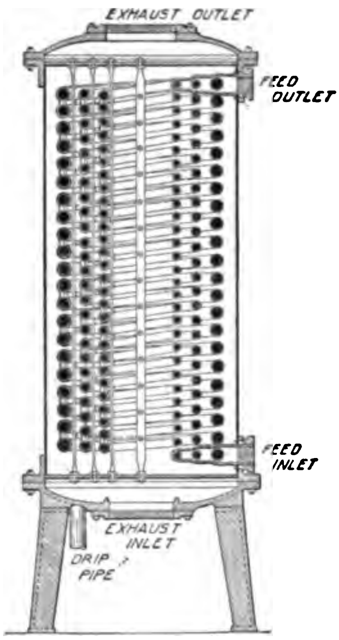


Fig. 49.

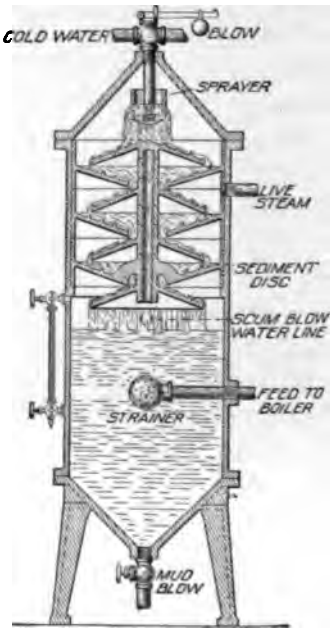
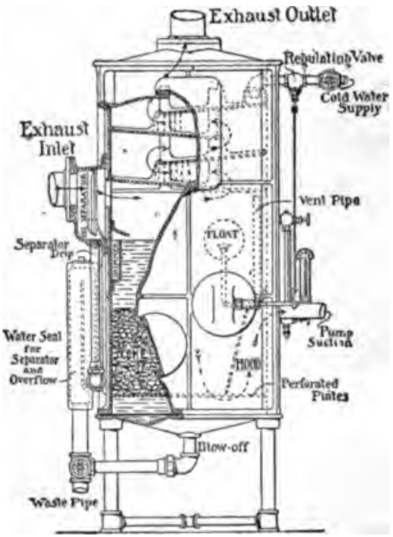


Fig. 50.

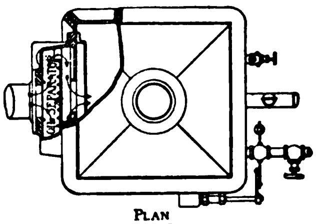
steam, or by the waste gases from the chimney. The apparatus used to heat feed water by exhaust steam are called feed water heaters; those which utilize waste gases are called economizers.

There are two types of **heaters**. The **open** and the **closed**. In the open heater the steam raises the temperature of the water by mingling with it, that is, by direct contact. The closed type of heater resembles a surface condenser; the exhaust steam surrounds copper or brass tubes which contain water, or the water circulates about tubes through which steam passes. Fig. 49 shows a feed water heater, of the closed type, the exhaust steam heating the feed water within the tubes. The heater shown in Fig. 50, is of the open type, the feed water becoming heated and depositing sediment while flowing from one tray to another.

The Cochrane heater, Fig. 51, is a combined heater and purifier. It is of the open heater type. The water enters at the top and flows in a thin sheet over a series of trays. The exhaust steam enters through the oil separator and rises among the trays, heating the water to about 210°F. The action is similar to that of a jet condenser. The gases in the feed water are liberated by the heat and escape into the atmosphere. The mineral impurities in solution, which cause scale, are precipitated by the heat and are deposited on the trays instead of on the plates and tubes of the boiler. The impurities, mud, clay, etc., which fall while the water is at rest, settle because of the large surface and consequent slight velocity. Coke, hay, etc., are used for filters; the heater being constructed so that the hay or coke will not enter the pump. The impurities having less specific gravity than the water, collect at the surface and are removed by flushing. Some of the advantages claimed for this heater are: *1.* The amount of cold water that can be heated is limited only by the quantity of exhaust steam. *2.* All the condensed exhaust is used because the oil is separated. *3.* It can be constructed of cast iron, which is cheap, durable, rarely pits, and resists corrosion. *4.* It is not likely



FRONT ELEVATION



PLAN

Fig. 51.

to crack or leak, because the internal pressure is rarely more than one pound above atmospheric pressure.

PUMPS AND INJECTORS.

Every boiler should have a reserve apparatus for pumping, or injecting the feed water.

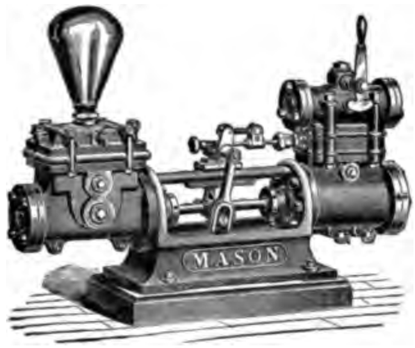


Fig. 52

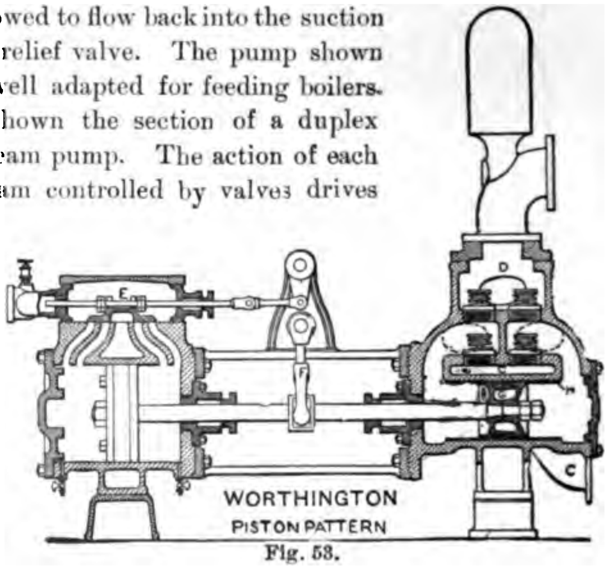


Fig. 53.

Boilers are usually fed by a small direct-acting **steam pump** placed near the boiler. Although these pumps require a large steam supply per horse-power per hour, the total amount of steam used is small because the work done is small. A more economical pump is the power pump driven by the large steam engine; but the rate at which water is supplied is not easily regulated to the demand of the boiler. They are usually arranged to pump a larger quantity of water than is required; the excess being allowed to flow back into the suction pipe through a relief valve. The pump shown in Fig. 52 is well adapted for feeding boilers. In Fig. 53 is shown the section of a duplex Worthington steam pump. The action of each is similar. Steam controlled by valves drives the piston in the steam cylinder, which moves the plunger in the water cylinder, since both are fastened to the same rod. The movement of the plunger forces a part of the water in front of it up through the valves into the air chamber and through the pipes into the boiler. On account of the partial vacuum caused by the movement of the plunger, water will be drawn from the suction pipe through the valves into the pump cylinder, filling the space left by the movement of the plunger. During the return stroke, this water is forced up into the air chamber and a like quantity enters the other end of the pump cylinder. The valves are kept on the seats by light springs, until the pressure on the bottom side is sufficient to lift them and allow water to flow through. When two pumps are placed side by side, and have a common delivery pipe, the machine is called a duplex pump. It is usual to set the steam valves so that when one piston is at the end, the other is at the middle of its stroke. A duplex pump having a large air chamber and valves set to act in this manner delivers water with an approximately constant velocity.

Water may be forced into a boiler by **injectors,** or **inspirators.** By means of this instrument, the energy of a jet of steam is used to force the water into the boiler. That there is sufficient energy to do this work is evident from the fact that each pound of steam in condensing gives up 966 B. T. U. and a B. T. U. is equivalent to 778 foot-pounds. All the energy of the jet of steam is not used in forcing water into the boiler; some is wasted and some is used to heat the feed water.

The action of the injector is briefly as follows. The steam escapes from the boiler with great velocity, and as it passes through the cone-shaped portion, draws air along with it and thus creates a partial vacuum in the suction pipe. Atmospheric pressure forces water up into the suction pipe, and the jet of steam which it meets is partly condensed. The energy of the jet carries the water along with it into the boiler.

Experiments show that the injector if considered as a pump has a very low efficiency. When used for feeding a boiler it has a thermal efficiency of nearly 100 per cent., since all the heat of the steam passes to the water except the slight amount lost in radiation. The pump, however, has one great advantage over the injector; it can force hot water from a heater into the boiler, while an injector can be used only with cold or moderately warm water.

Figs. 54 and 55 show the interior section and exterior of a Hancock Inspirator. To inject water to the boiler, first open Overflow valves 1 and 3, close valve 2 and open Starting valve in the steam pipe. When the water appears at the Overflow close 1, open 2 one-quarter turn and then close 3. The inspirator will then be in operation. When the inspirator is not working, open both 1 and 3 to allow water to drain from it.

Both temperature and quantity of delivery water can be varied by increasing or decreasing the water supply. When the water in the suction pipe is hot, either cool off both pipe and injector with cold water, or pump out the hot water by opening and closing the Starting valve suddenly. The following table gives some dimensions and capacities of the different sizes.

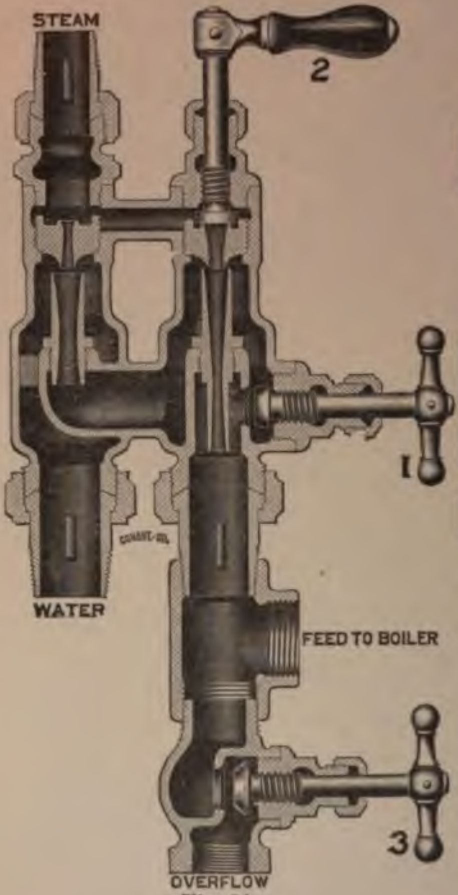


Fig. 54.

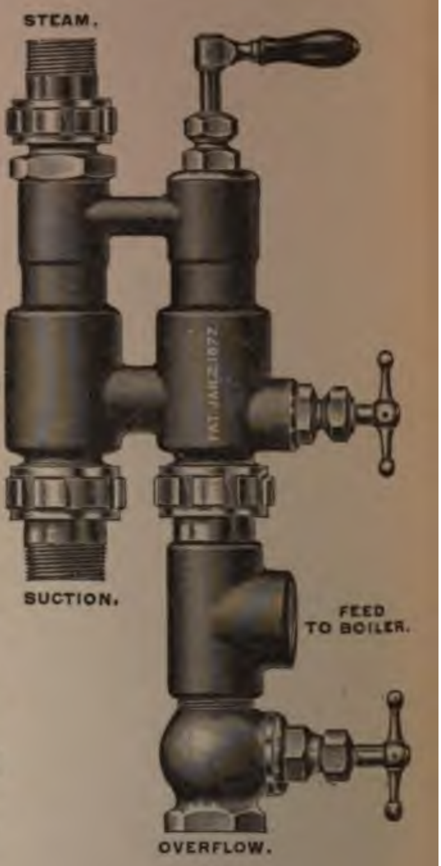


Fig. 55.

THE HANCOCK INSPIRATOR.

	CAPACITIES PER HOUR.		PIPE CONNECTIONS.			
SIZE. (number)	With 60 lbs. Steam Pressure and 4 ft. Lift.	Maximum Horse Power.	Steam.	Suction.	Delivery.	Overflow.
7½	60 gals.	8	⅜	⅜	⅜	¼
8¾	90 "	12	⅜	½	½	⅜
10	120 "	16	⅜	½	½	⅜
12½	220 "	30	½	¾	¾	½
15	300 "	40	½	¾	¾	½
17½	420 "	56	¾	1	1	¾
20	540 "	72	¾.	1	1	¾
22½	720 "	96	1	1¼	1¼	1
25	900 "	120	1	1¼	1¼	1
30	1,260 "	168	1¼	1½	1½	1¼
35	1,740 "	230	1¼	1½	1½	1¼
40	2,230 "	298	1½	2	2	1½
45	2,820 "	376	1½	2	2	1½
50	3,480 "	464	2	2½	2½	2
55	3,650 "	600	2	2½	2½	2

PIPES AND PIPE COVERINGS.

Piping a steam plant must be carefully done. The pipes should be large enough, well lagged, and so placed and arranged that there will be slight steam friction and as little condensation as possible. The steam pipe leading from the boiler called the main steam pipe or "log," is usually made of cast iron. It is made in sections flanged and bolted together.

Changes of temperature cause expansion and contraction of the steam pipes, and if no provision is made for expansion, the pipes or fittings may crack, or the joints become loosened and leak. If a pipe is long and straight, some form of expansion joint is generally used. A bend or elbow will allow the pipe to expand without injury to itself or boiler. There are various other methods; the use of a curved copper pipe shaped like an inverted U; expansion joints, etc. If a slip joint is employed it should be in line to prevent its becoming cramped.

If high pressures are used, steel pipe is better than cast iron, for it is much stronger, more flexible and reliable.

If a stop valve is placed in a vertical pipe, the portion of the pipe above the valve will fill up with water when the valve is closed. In order that the water may not be blown over to the engine a drip pipe or a steam trap should be used. The pipe which supplies an engine, usually has a drip pipe above the throttle valve.

In case horizontal pipes are arranged so that water may collect in them, any increase in the velocity or the sudden opening of a valve will sweep the water along with the steam. This water causes considerable damage to the engine and also to the pipe. The sudden rush of water against elbows is likely to cause leakage if not actual bursting.

The true inside diameter of a steam, gas or water pipe is not always the same as the name of the pipe indicates. For instance what is called a 3-inch pipe has an actual inside diameter of 3.067 inches and an outside diameter of 3.5.

The following table gives the principal dimensions of steam pipes.

Standard Sizes, etc., of Wrought Iron Pipe for Water, Gas, or Steam.

(Briggs Standard.)

DIAMETER OF TUBE.			Thickness of Metal.	Internal Circumference.	External Circumference.	Internal Area.	External Area.
Nominal Inside.	Actual Inside.	Actual Outside.					
INS.	INS.	INS.	INS.	INS.	INS.	INS.	INS.
⅛	.270	.405	.068	.848	1.272	.0572	.129
¼	.364	.540	.088	1.144	1.696	.1041	.229
⅜	.494	.675	.091	1.552	2.121	.1916	.358
½	.623	.840	.109	1.957	2.652	.3048	.554
¾	.824	1.050	.113	2.589	3.299	.5333	.866
1	1.048	1.315	.134	3.292	4.134	.8627	1.357
1¼	1.380	1.660	.140	4.335	5.215	1.496	2.164
1½	1.610	1.900	.145	5.061	5.969	2.038	2.835
2	2.067	2.375	.154	6.494	7.461	3.355	4.430
2½	2.468	2.875	.204	7.754	9.032	4.783	6.491
3	3.067	3.500	.217	9.636	10.996	7.388	9.621
3½	3.548	4.000	.226	11.146	12.566	9.887	12.566
4	4.026	4.500	.237	12.648	14.137	12.730	15.904
4½	4.508	5.000	.246	14.153	15.708	15.939	19.635
5	5.045	5.563	.259	15.849	17.475	19.990	24.299
6	6.065	6.625	.280	19.054	20.813	28.889	34.471
7	7.023	7.625	.301	22.063	23.954	38.737	45.663
8	7.982	8.625	.322	25.076	27.096	50.039	58.426
10	10.019	10.750	.366	31.475	33.772	78.838	90.762

If the area of a steam pipe is small there will be considerable loss in pressure due to friction. It is usual to limit the velocity of live steam in pipes to 5,000 or 6,000 feet per minute. If there are many elbows or bends the allowable velocity may be reduced to 4,500 feet or less.

Suppose we wish to find the **diameter** of the **main steam pipe** from the boilers to the engines. The engines furnish 4,500 horse-power and use 20 pounds of steam per horse-power per hour. Also the pressure is 105 pounds absolute, that is, about 90 pounds by gage.

The total amount of steam furnished per minute will be,

$$4{,}500 \times 20 \div 60 = 1{,}500 \text{ pounds.}$$

Since one pound of steam at 105 pounds absolute pressure has a volume of 4.205 cubic feet, the total volume of steam passing through the pipe per minute will be $1{,}500 \times 4.205 = 6{,}307.5$ cubic feet. Then if we allow a velocity of 5,000 feet per minute the area will be $\frac{6307.5}{5000} = 1.26$ square feet (approx.) If the pipe has 1.26 square feet or 181 inches of area it would be 15.2 + inches in diameter. The pipe used would be the next size, that is, 16 inches.

The **thickness** of pipes has been discussed in Mechanics. For copper pipes Unwin gives the following formula:

$$t = .0001\, p\, d + \tfrac{1}{8},$$

in which t is the thickness in inches, p the steam gage pressure, d the diameter and $\frac{1}{8}$ a constant.

To find the thickness of a copper pipe $3\frac{1}{2}$ inches in diameter, with a steam pressure of 80 pounds; $t = .0001\, p\, d + \frac{1}{8} = .0001 \times 80 \times 3\frac{1}{2} + \frac{1}{8} = .153$ inch.

The sections of the main steam pipe are bolted together at the flanges. The joint is made tight by machining the flanges and inserting between them a packing ring of India rubber, asbestos, or gutta percha. Sometimes a corrugated copper ring is used in place of the rubber, or a groove cut in the flanges, in which is fitted a copper wire.

Water in steam pipes causes **water hammer.** For this reason the pipes should be arranged or provided with drip pipes, traps, separators, etc., so that the pipes will not be injured.

In order to return the water of condensation from a drip, trap, or separator to the boiler, a **steam loop** is used. It consists of a

The Barrel Calorimeter was invented by the distinguished Alsatian engineer, Mr. G. A. Hirn. It is one of the earliest forms and is used only when more accurate and expensive apparatus cannot be obtained.

As many corrections are required, it is recommended only for approximate results. It consists of a barrel holding at least 400 pounds of water, and an iron pipe having a valve. This pipe is connected with the source from which steam is to be taken, and the end has a hose provided at its extremity with a cap closed at the end, but perforated on its side with a number of holes. A propeller is placed in the barrel for stirring the water, so as to obtain as nearly as possible a uniform temperature. The whole is then placed upon platform scales, as illustrated in Fig. 56. To use, the barrel is first filled about two-thirds with cold water, carefully weighed, and its temperature noted. Before immersing the hose in the barrel, steam is allowed to flow through the pipe and hose until they are thoroughly warmed. The hose is then plunged into the barrel and steam allowed to flow until a sufficient amount is obtained; the valve is then closed, the hose removed, and the resulting mixture weighed and temperature noted. The calculation is made by the use of the following formula:

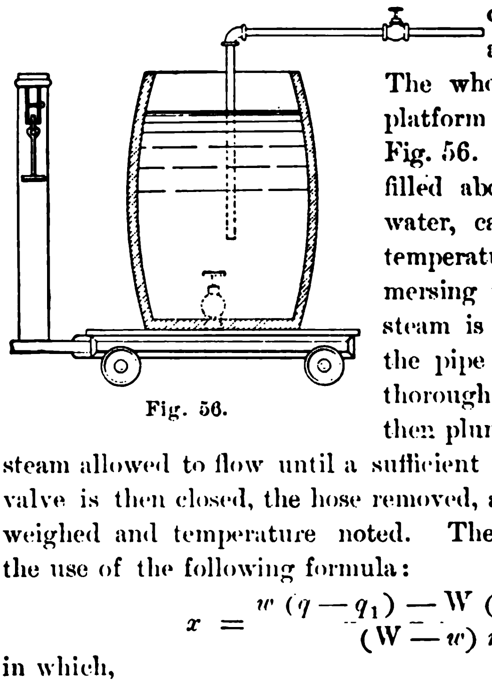


Fig. 56.

$$x = \frac{w\,(q - q_1) - W\,(q - q_2)}{(W - w)\,r}$$

in which,

x = the weight of steam contained in one pound of the mixture from the boiler or other source,

w = the weight of the cooling or condensing water,

W = the final weight of the water in the barrel,

q = the heat of the liquid mixed with the steam,

q_1 = the heat of one pound of the cooling water before the mixture from the boiler is added,

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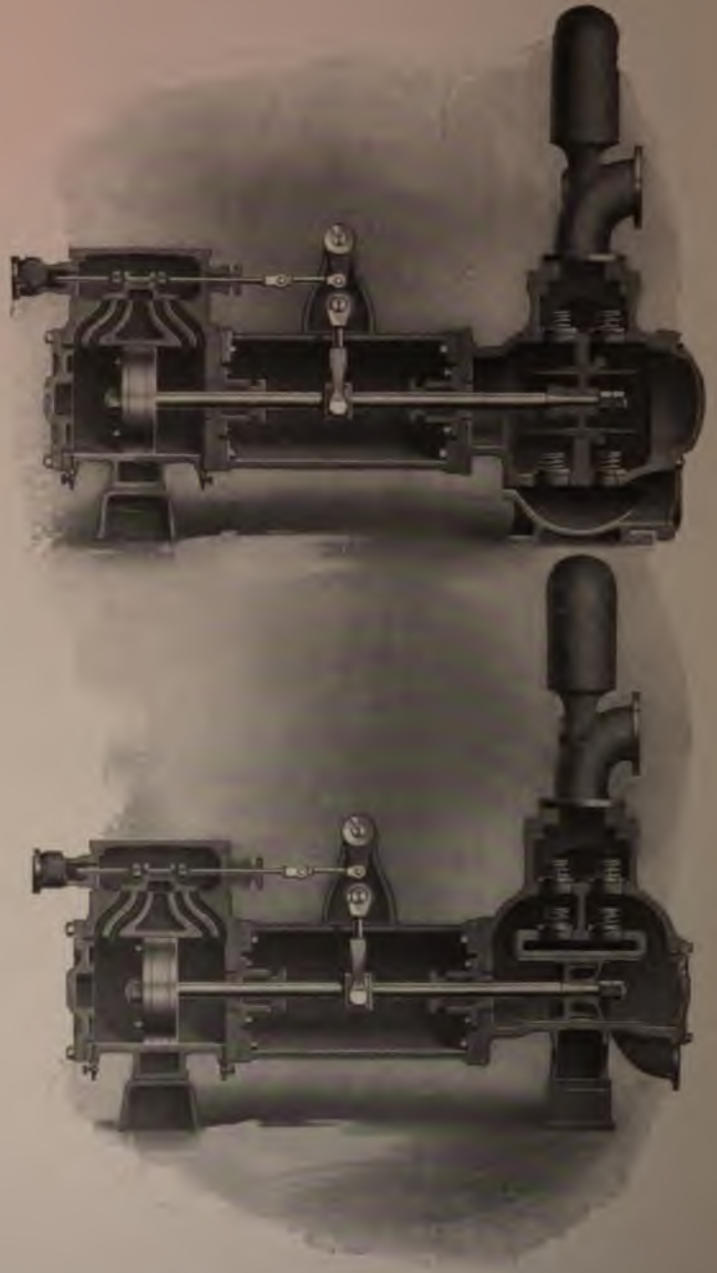

WORTHINGTON STEAM PUMP, SHOWING ARRANGEMENT OF WORKING PARTS.

q_2 = the heat of one pound of the water after the mixture from the boiler is added,

[*]r = the heat of evaporation corresponding to the absolute pressure at the source of supply.

If x is greater than 1 it shows that the steam is superheated, the number of degrees of superheating being equal to

$$2.0833\ r\ (x - 1).$$

Example: Let $w = 455$ pounds, $W = 495$ pounds,

$q = 276.9$, corresponding to an absolute pressure of 75 pounds,

$r = 898.8$ the corresponding heat of evaporation,

$q_1 = 18.10$, corresponding to a temperature of 50° F., the initial temperature of the cooling water,

$q_2 = 108.2$, corresponding to a temperature of 140° F., the final temperature of the water in the barrel, then:

$$x = \frac{455\ (276.9 - 18.10) - 495\ (276.9 - 108.2)}{(495 - 455) \times 898.8}$$

$= 0.952$ pound or 95.2 per cent, or the moisture $= 1 - 0.952 = 0.048$ of a pound or 4.8 per cent.

A slight error either in weighing or in taking the temperature may cause a large error in the result. The above formula is based upon the assumption that there is no loss from radiation.

Separator Calorimeter.[†] This instrument consists of a chamber, A, Fig. 57, about a foot long and three inches in diameter, into which is led a steam-pipe D from the boiler, the extension of this pipe being enlarged within the chamber A. The lower end of the pipe D is perforated with a number of holes, each $\frac{1}{8}$ inch in diameter. The steam escapes from the calorimeter through the pipe S, in which is secured a diaphragm having a hole in its center $\frac{1}{16}$ inch in diameter. On entering the calorimeter by the pipe D the velocity of the steam is reduced, owing to the enlargement, and the particles of water are carried to the bottom of the chamber while the steam rises to the top, escaping at S, as mentioned. A water-glass G is attached, as shown. The height of the water in the glass at the beginning is noted and marked by a string or other means, and the water is again brought to the same level at the end of the test, by opening the cock E, and the amount drained very accurately weighed. The results may be calculated by aid of the following formula:

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[*] NOTE.—Some authors use t with suffixes, instead of q with suffixes, L instead of r, and Q instead of x.

[†] The invention of Professor R. C. Carpenter.

$$x = \frac{w_1 + W}{W + w}$$

where

x = the weight of steam contained in one pound of the mixture,

W = weight of steam discharged from the pipe S,

w = weight of water drawn through the cock E,

w_1 = weight of steam condensed by loss of heat due to radiation.

The loss w_1 may be determined by uniting two instruments, the first one discharging its steam through S, in which case no diaphragm is used, into the steam-pipe D of the second, the amount of water collected in the second being that due to the loss by radiation, since the first supplies the second with steam only.

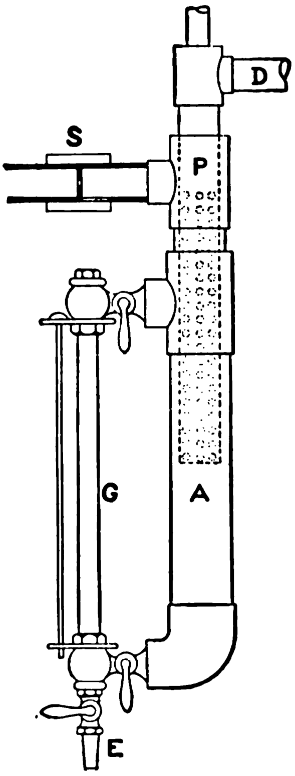


Fig. 57.

Example:

W = 10 pounds,

w = 6 ounces, = $\frac{3}{8}$ of a pound,

w^1 = 2 ounces, = $\frac{1}{8}$ of a pound,

from which we obtain

$$x = \frac{\frac{1}{8} + 10}{10 + \frac{3}{8}} = 0.9759 \text{ of a pound, or } 97.59 \text{ per cent.}$$

The moisture is then:

1 — 0.9759 or 0.0241 of a pound, or 2.41 per cent.

In using this instrument gages and thermometers are not required, as it depends upon weighing the steam and water.

The Throttling Calorimeter was invented by Professor Cecil H. Peabody and is made with varying constructive details.

Fig. 58 shows the general arrangement. The mixture of steam and water from the boiler is taken from the main steam-pipe through what is termed a sampling pipe. Various forms of this pipe are made; one arrangement consists of a pipe closed at its inner end, but having numerous holes $\frac{1}{4}$ inch in diameter drilled staggering around the sides. The calorimeter should be placed as close as possible to the main steam pipe and the gage for indicating the pressure in the main steam pipe on the latter and near the calorimeter. The gage is sometimes connected to a tee on the pipe leading to the calorimeter, but it is better to have this gage where the velocity of the flowing steam is less. A valve is placed in the pipe to the calorimeter, below which is inserted a nipple, A, having a small converging orifice, D, about two-tenths of an inch in diameter and very carefully made. The object of such an orifice is to determine the weight of steam flowing through the calorimeter so an allowance can be made for the loss when testing an engine, or boiler, where the net weight used is required. A cup, B, is screwed into the top for holding an accurate thermometer. The cup is made of brass and is filled with oil, but if mercury is used the cup must be of iron or steel. A delicate gage, C, for determining the pressure in the calorimeter and a pipe and valves at the bottom complete the apparatus. The valve N is sometimes omitted and a simple pipe used, as the throttling is best accomplished by use of the valve E, or orifice D. All pipes leading to the calorimeter should be well covered with a good non-conductor. To use the instrument proceed

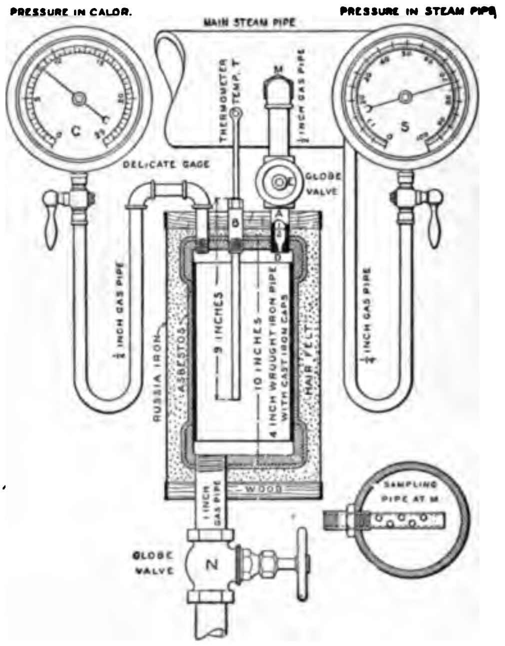


Fig. 58.

as follows : Open wide valves E and N, to bring the apparatus to a uniform temperature, then gradually close E until the steam in the calorimeter is superheated; that is, until the temperature as shown by the thermometer is greater than that corresponding to the absolute pressure determined from the reading of the gage C and barometric pressure. The result may now be calculated by the following formula:

$$x = \frac{\lambda_c + 0.48\,(T - t_c) - q_s}{r_s}$$

in which

x = the weight of steam contained in one pound of the mixture from the main steam pipe or other source,

λ_c = the total heat corresponding to the absolute pressure determined from the reading of the gage C and barometric pressure.*

T = the temperature as shown by the thermometer,

t_c = the temperature of steam corresponding to the absolute pressure as determined by the reading of the gage C and barometric pressure,

q_s = the heat of the liquid corresponding to the absolute pressure in the steam pipe,

r_s = the heat of evaporation corresponding to the absolute pressure in the steam pipe,

0.48 = the heat required to superheat the steam one degree Fahrenheit under constant pressure.

Example:

Barometric pressure 14.78 lbs. Absolute pressure in the main steam pipe 87.78 lbs. Absolute pressure in the calorimeter 23.03 lbs. Temperature T = 260° F.,

Then

$\lambda_c = 1153.68$ $\qquad$ $q_s = 288.1$

$t_c = 235.28$ $\qquad$ $r_s = 890.88$

and

$$x = \frac{1153.68 + .48\,(260 - 235.28) - 288.1}{890.88}$$

= 0.984 of a pound, or 98.4 per cent of the mixture is steam, or the moisture = (1 − 0.984) = 0.016 of a pound, or 1.4 per cent.

*Some steam tables use H instead of the Greek letter λ (lambda).

This form of calorimeter is suitable only for cases where the moisture does not exceed three per cent of the mixture. Its principle is based upon the assumption that there is no loss of heat, in which case steam mixed with a small amount of water is superheated when the pressure is reduced by throttling.

HORSE-POWER OF BOILERS.

The unit which we call the horse-power is *arbitrary*. Assuming that 30 pounds of steam are required per horse-power per hour for an average engine, this unit for boilers has been adopted.

One (1) horse-power is the evaporation of 30 pounds of water per hour, from a temperature of 100° F. into steam at 70 pounds gauge pressure. This is considered equivalent to the evaporation of 34½ pounds per hour from and at 212° F. A horse-power is equal to 33,327 B. T. U. per hour.

As all boilers do not generate steam at the same pressure and from the same temperature of feed water, it is necessary to reduce the **actual** evaporation to an **equivalent** evaporation. Unless this is done their relative performances cannot be compared.

For this comparison, the actual evaporation is reduced to the equivalent evaporation from and at 212° F. That is, we suppose the water to be fed at 212° and evaporated into steam at 212°.

Let W = the water actually evaporated in pounds,
H = the total heat of steam above 32°F., at actual pressure,
T = temperature of feed water,
w = equivalent evaporation from and at 212°F.:

Since 966 B. T. U. are necessary to evaporate one pound of water from and at 212°F., the equivalent evaporation may be found from the formula,

$$W(H + 32 - T) = 966w, \text{ or } w = \frac{W(H + 32 - T)}{966}.$$

Then the horse-power of the boiler is,

$$\text{H. P.} = \frac{w}{34.5}.$$

The above method is considerably shortened by substituting for the quantity $\frac{H + 32 - T}{966}$, the number found in the following table which corrresponds to the actual feed water temperature and steam pressure.

FACTORS OF EVAPORATION.

Temperature Feed-Water. Fahrenheit.	PRESSURE IN POUNDS PER SQUARE INCH ABOVE THE ATMOSPHERE. (GAGE PRESSURE.)																					Temperature Feed-Water. Fahrenheit.
	0	5.	15.	25.	35.	45.	55.	65.	75.	85.	95.	105.	115.	125.	135.	145.	155.	165.	175.	185.	200.	
Degr's																						Degr's
32	1.187	1.192	1.199	1.204	1.209	1.212	1.216	1.218	1.221	1.223	1.226	1.228	1.230	1.231	1.233	1.235	1.236	1.238	1.239	1.240	1.241	32
35	1.184	1.189	1.196	1.201	1.206	1.209	1.213	1.215	1.218	1.220	1.223	1.225	1.227	1.228	1.230	1.232	1.233	1.235	1.236	1.237	1.238	35
40	1.179	1.184	1.191	1.196	1.201	1.204	1.208	1.219	1.213	1.215	1.218	1.220	1.222	1.223	1.225	1.227	1.228	1.230	1.231	1.232	1.233	40
45	1.173	1.178	1.185	1.190	1.195	1.198	1.202	1.204	1.207	1.209	1.212	1.214	1.216	1.217	1.219	1.221	1.222	1.224	1.225	1.226	1.227	45
50	1.168	1.173	1.180	1.185	1.190	1.193	1.197	1.199	1.202	1.204	1.207	1.209	1.211	1.212	1.214	1.216	1.217	1.219	1.220	1.221	1.222	50
55	1.163	1.168	1.175	1.180	1.185	1.188	1.192	1.194	1.197	1.199	1.202	1.204	1.206	1.207	1.209	1.211	1.212	1.214	1.215	1.216	1.217	55
60	1.158	1.163	1.170	1.175	1.180	1.183	1.187	1.189	1.192	1.194	1.197	1.199	1.201	1.202	1.204	1.206	1.207	1.209	1.210	1.211	1.212	60
65	1.153	1.158	1.165	1.170	1.175	1.178	1.182	1.184	1.187	1.189	1.192	1.194	1.196	1.197	1.199	1.201	1.202	1.204	1.205	1.206	1.207	65
70	1.148	1.153	1.160	1.165	1.170	1.173	1.177	1.179	1.182	1.184	1.187	1.189	1.191	1.192	1.194	1.196	1.197	1.199	1.200	1.201	1.202	70
75	1.143	1.148	1.155	1.160	1.165	1.168	1.172	1.174	1.177	1.179	1.182	1.184	1.186	1.187	1.189	1.191	1.192	1.194	1.195	1.196	1.197	75
80	1.137	1.142	1.149	1.154	1.159	1.162	1.166	1.168	1.171	1.173	1.176	1.178	1.180	1.181	1.183	1.185	1.186	1.188	1.189	1.190	1.191	80
85	1.132	1.137	1.144	1.149	1.154	1.157	1.161	1.163	1.166	1.168	1.171	1.173	1.175	1.176	1.178	1.180	1.181	1.183	1.184	1.185	1.186	85
90	1.127	1.132	1.139	1.144	1.149	1.152	1.156	1.158	1.161	1.163	1.166	1.168	1.170	1.171	1.173	1.175	1.176	1.178	1.179	1.180	1.181	90
95	1.122	1.127	1.134	1.139	1.144	1.147	1.151	1.153	1.156	1.158	1.161	1.163	1.165	1.166	1.168	1.170	1.171	1.173	1.174	1.175	1.176	95
100	1.117	1.122	1.129	1.134	1.139	1.142	1.146	1.148	1.151	1.153	1.156	1.158	1.160	1.161	1.163	1.165	1.166	1.168	1.169	1.170	1.171	100
105	1.111	1.116	1.123	1.128	1.133	1.136	1.140	1.142	1.145	1.147	1.150	1.152	1.154	1.155	1.157	1.159	1.160	1.162	1.163	1.164	1.165	105
110	1.106	1.111	1.118	1.123	1.128	1.131	1.135	1.137	1.140	1.142	1.145	1.147	1.149	1.150	1.152	1.154	1.155	1.157	1.158	1.159	1.160	110
115	1.101	1.106	1.113	1.118	1.123	1.126	1.130	1.132	1.135	1.137	1.140	1.142	1.144	1.145	1.147	1.149	1.150	1.152	1.153	1.154	1.155	115
120	1.096	1.101	1.108	1.113	1.118	1.121	1.125	1.127	1.130	1.132	1.135	1.137	1.139	1.140	1.142	1.144	1.145	1.147	1.148	1.149	1.150	120
125	1.091	1.096	1.103	1.108	1.113	1.116	1.120	1.122	1.125	1.127	1.130	1.132	1.134	1.135	1.137	1.139	1.140	1.142	1.143	1.144	1.145	125
130	1.085	1.090	1.097	1.102	1.107	1.110	1.114	1.116	1.119	1.121	1.124	1.126	1.128	1.129	1.131	1.133	1.134	1.136	1.137	1.138	.139	130
135	1.080	1.085	1.092	1.097	1.102	1.105	1.109	1.111	1.114	1.116	1.119	1.121	1.123	1.124	1.126	1.128	1.129	1.131	1.132	1.133	1.134	135
140	1.075	1.080	1.087	1.092	1.097	1.100	1.104	1.106	1.109	1.111	1.114	1.116	1.118	1.119	1.121	1.123	1.124	1.126	1.127	1.128	1.129	140
145	1.070	1.075	1.082	1.087	1.092	1.095	1.099	1.101	1.104	1.106	1.109	1.111	1.113	1.114	1.116	1.118	1.119	1.121	.122	1.123	1.124	145
150	1.065	1.070	1.077	1.082	1.087	1.090	1.094	1.096	1.099	.101	1.104	1.106	1.108	1.109	1.111	1.113	1.114	1.116	.117	1.118	1.119	150
155	1.059	1.064	1.071	1.076	1.081	1.084	1.088	1.090	1.094	1.095	1.098	1.100	1.102	1.103	1.105	1.107	1.108	1.110	1.111	.112	1.113	155
160	1.054	1.059	1.066	1.071	1.076	1.079	1.083	1.085	1.088	1.090	1.093	1.095	1.097	1.098	1.100	1.102	1.103	1.105	1.106	107	1.108	160
165	1.049	1.054	1.061	1.066	1.071	1.074	1.078	1.080	1.083	.085	1.088	.090	1.092	1.093	1.095	1.097	1.098	1.100	101	1.102	1.103	165
170	1.044	1.049	1.056	1.061	1.066	1.069	1.073	1.075	1.078	.080	.083	1.085	1.087	1.088	1.090	1.092	1.093	1.095	.096	1.097	1.098	170
175	1.039	1.044	1.051	1.056	1.061	1.064	1.068	1.070	1.073	.075	.078	1.080	1.082	1.083	1.085	1.087	1.088	1.090	.091	1.092	1.093	175
180	1.033	1.038	1.045	1.050	1.055	1.058	1.062	1.064	1.067	.069	.072	1.074	1.076	1.077	1.079	1.081	1.082	1.084	.085	1.086	1.087	180
185	1.028	1.033	1.040	1.045	1.050	1.053	1.057	1.059	1.062	1.064	.067	1.069	1.071	1.073	1.074	1.076	1.077	1.079	.080	1.081	1.082	185
190	1.023	1.028	1.035	1.040	1.045	1.048	1.052	1.054	1.057	1.059	.062	.064	1.066	1.067	1.069	1.071	1.072	1.074	.075	1.076	1.077	190
195	1.018	1.023	1.030	1.035	1.040	1.043	1.047	1.049	1.052	1.054	.057	.059	1.061	1.062	1.064	1.066	1.067	1.069	.070	1.071	1.072	195
200	1.013	1.018	1.025	1.030	1.035	1.038	1.042	1.044	1.047	1.049	.052	.054	1.056	1.057	1.059	1.061	1.062	1.064	.065	1.066	1.067	200
205	1.001	1.012	1.019	1.021	1.029	1.032	1.036	1.038	1.041	1.043	1.046	.048	1.050	1.051	1.053	1.055	1.056	1.058	.059	1.060	.062	205
210	1.002	1.007	1.014	1.019	1.024	1.027	1.031	1.033	1.036	1.038	1.041	.043	1.045	1.046	1.048	1.050	1.051	1.053	.054	1.055	.057	210
212	1.000	1.005	1.012	1.017	1.022	1.025	1.029	1.031	1.034	1.036	1.039	.041	1.043	1.044	1.046	1.048	1.049	1.051	.052	1.053	.056	212

For example : A boiler is required to furnish 2100 pounds of steam per hour. If the gage pressure is 85 pounds and the feed water enters at 50°F., what is the equivalent evaporation and what is the horse-power ?

From the table the factor for 85 pounds pressure and 50° F. is 1.204. Then the equivalent evaporation would be $1.204 \times 2100 = 2528.4$ pounds, and $\frac{2528.4}{34.5} = 73$ (approx.) = the H. P.

BOILER SETTING.

The setting for a stationary boiler consists of the foundation and as much of the furnace and flues as are external to the boiler shell. Some internally fired boilers, the Lancashire for instance, have flues in the brick setting. The whole furnace and sometimes the flues, as is the case with the plain cylindrical boiler, are in the setting. Vertical boilers have simply a foundation, and locomotive boilers have no setting since they are supported by the frames of the engines. Marine boilers are usually placed on saddles, which are built into the framing of the vessel.

In setting a boiler there are three principal requisites that should be kept in mind. *1.* A stable support or foundation for the shell. *2.* Properly arranged spaces for both furnace flues and ash-pit. *3.* A covering which shall prevent loss of heat by radiation and that will not keep moisture in contact with the plates.

There are two principal methods for support; by **brackets** riveted to the shell plates and by supporting from **overhead girders** by means of hooks, rings, etc. In any case the supports should be so arranged that each shall bear its proper proportion of the load and at the same time allow for expansion. If the boiler is short, brackets are generally used, while for long, plain cylindrical boilers the girder method is the more common. If a very long, cylindrical boiler is supported only at each end, the great weight between the two supports is likely to cause bending and an excessive strain on the lower plates at the middle.

The first requisite for a setting is a good **foundation.** If the ground is firm and favorable to a solid foundation, the excavation need be only three or four feet below the level. If it is soft, the excavation should be deeper and the extra depth filled in with broken stone mixed in with cement, gravel, etc. The first course of the foundation should be large stones laid in cement; upon this stone work the walls are built, either of stone or brick to within about six inches of the floor level and above this, brick should be used.

In determining the **area** of the bed, the weight that can be put on one square foot should be estimated carefully. With ordinary condition of the soil, the weight per square foot should not exceed 2000 pounds.

Sometimes the bed is made of concrete about two feet in thickness. If the soil is very firm a foundation of large stonework about three feet wide is built under the side, middle and end walls.

The **supporting** and **enclosing** walls are built upon this foundation. The outer walls at the sides and rear are double; the space between, usually about two inches, being an air space to prevent loss of heat. Projecting bricks, which extend from the outer until they just touch the inner, allow for expansion without decreasing the strength of the inner wall. Fig. 59 shows a boiler in the brick setting. The boiler is supported by brackets. The front brackets rest on iron plates which are built into the walls and the rear brackets are free to move, being supported by rollers. If the furnace is designed for anthracite coal the distance between the shell and the grate bars is about two feet; for softer coal this distance is increased a few inches. The grates have an incline of a few inches so the bed of coal will be thicker at the rear than at the front; this allows a more even consumption of fuel as the air passes through the fire at the bridge more freely. The furnace, both front and sides, and sometimes portions back of the bridge, are lined with firebrick. The bridge also is generally covered with firebrick. The space between the bridge and the shell is from 6 to 8 inches. The rear walls are built a little higher than the top row of tubes. The fire line should not be carried above the water line; if it is, the intense heat is likely to injure the shell plates. Never expose any part of the boiler not covered by water to the gases from the fire. The side walls are built about the same height as the rear walls. The space at the rear is bridged over and stiffened by T irons. In order to increase the heating surface

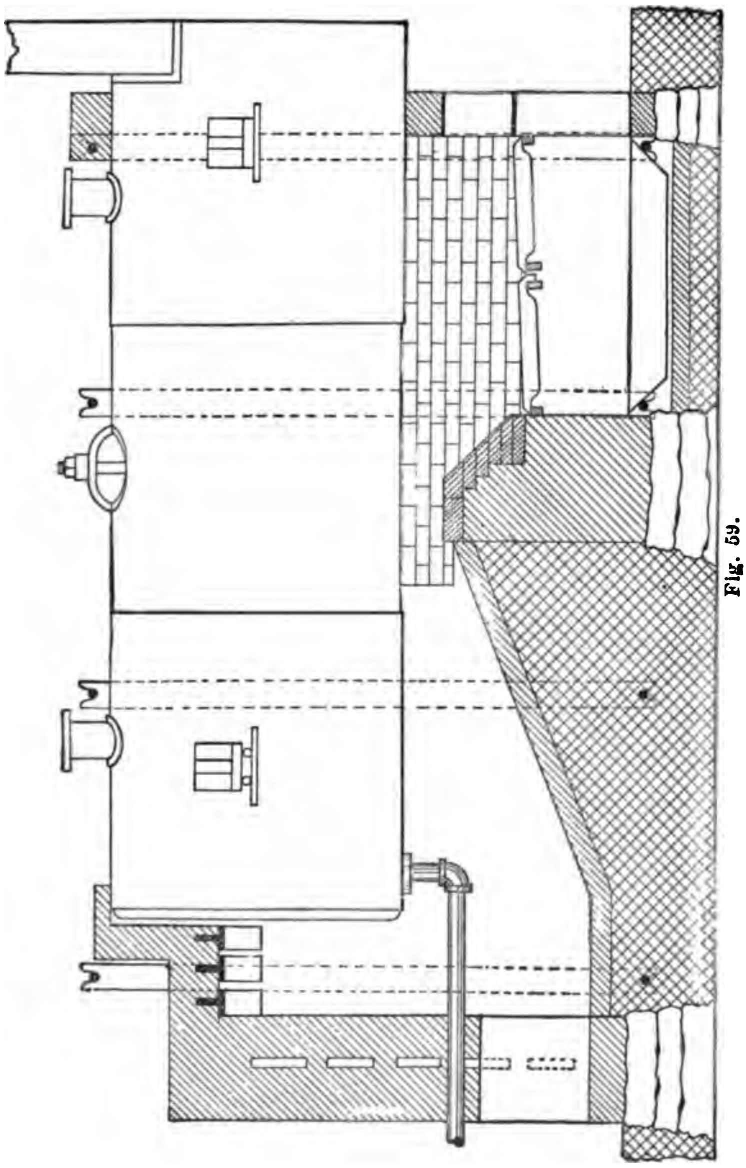


Fig. 59.

the top is arched so that the hot gases will pass over the steam space before they enter the chimney.

The smoke box projects over the front wall and has a rectangular uptake. The side walls are strengthened by buckstaves or binders, which are kept in place by long bolts, secured by nuts on each end, as shown in Fig. 60.

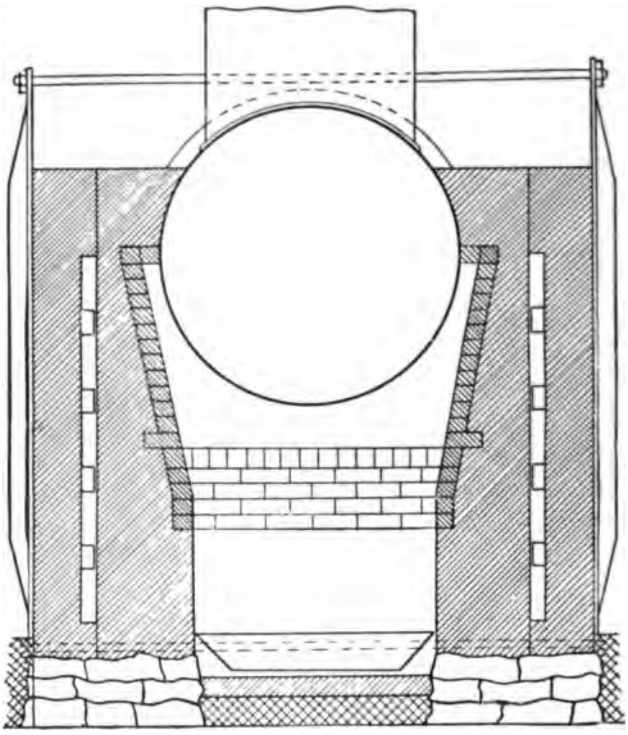


Fig. 60.

Fig. 61 shows the top view of the same boiler.

The front is usually of cast iron with doors for firing, cleaning and for access to the tubes. Soot, dirt, etc., are removed through the door in the brickwork at the rear.

The end which contains the handhole should be set about one inch **lower** than the other end, so that the sediment and detached scale will tend to accumulate there.

Internally fired boilers may also be enclosed in brickwork. The setting is a support and covering, forming the side flues but

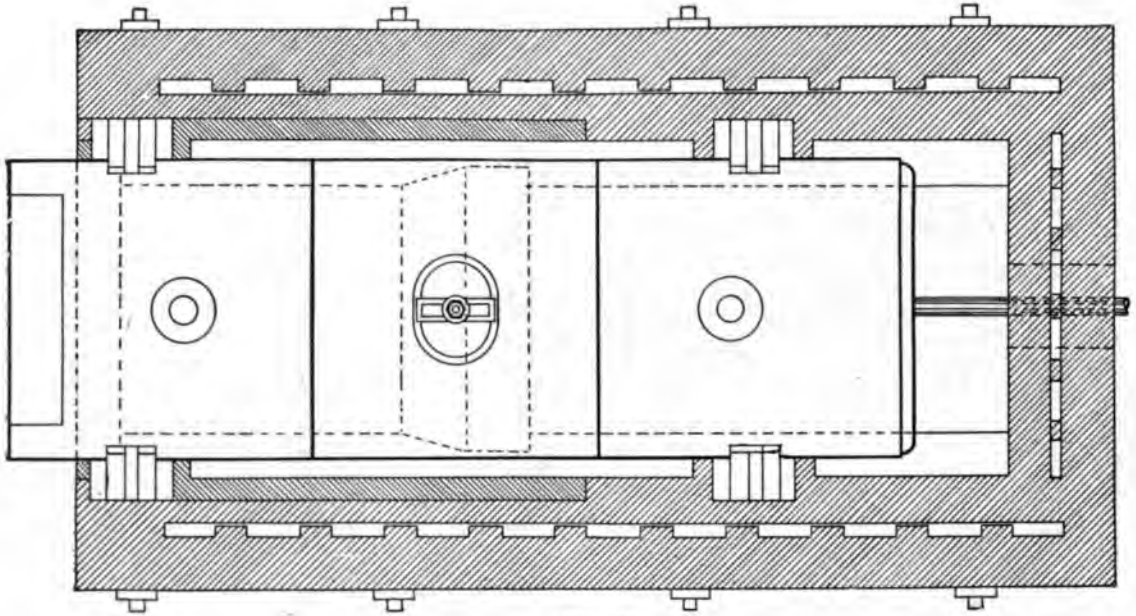


Fig. 61.

not the furnace. Excess of brickwork surface in contact with the shell should be avoided, as brickwork collects moisture which causes external corrosion.

Water Tube Boilers. The settings for water tube boilers are similar to the settings of cylindrical tubular boilers. In "Types of Boilers," the various settings were mentioned. In such boilers as the Babcock and Wilcox, Heine and Stirling, special bridges and tiling are required to conduct the gases and keep them in contact with the tubes. The Cahall boiler is set in a vertical stack, with the furnace at one side.

Marine water tube boilers, as the Almy and Thornycroft are enclosed in sheet iron casing which is lined with non-conducting material; usually asbestos or magnesia.

CORROSION AND INCRUSTATION.

There are several forces which tend to **destroy** and **shorten** the life of every boiler. These forces are divided into two general classes; chemical and mechanical. Impure feed water may injure the boiler in two ways; it may **corrode** the iron, or it may **deposit sediment** that forms scale.

Pure water, free from air and carbon dioxide, has no bad effect on iron; but all natural waters, whether from rain, lake, river, or sea contain air in solution and a little carbon dioxide. Water that contains gases or acids attacks iron readily.

Corrosion. There are two forms of corrosion, **external** and **internal.** External corrosion is caused by exposure to the weather, moisture from the ground, or leakage of joints and fittings. In time a slight leakage from a joint may cause considerable corrosion. A large amount of the deterioration from external corrosion is due to the practice of setting boilers in a mass of brickwork. The brickwork holds any water that may come in contact with the plates. When an internally fired boiler is placed on a wide mid-feather, or supporting wall, all the water from leakage or any other source finds its way to the bottom of the boiler and is kept in contact with the plates by the wall. Mid-feather walls extend beneath the boiler nearly from end to end and are sometimes 18 to 24 inches wide. It is impossible to know from **external appearance,** the condition of the plates resting on the brickwork. The plates at the edge may appear to be in good condition yet the center portions may be eaten nearly through. If a mid-feather wall is used it should not be more than three or four inches wide, and a few bricks should be loose to permit inspection. When the ground is damp, plates placed between the walls and the shell are exposed to the moisture, thus saving the boiler plates.

Internal corrosion appears in various forms; **general corrosion** or wasting, **pitting** or honeycombing and **grooving**. General corrosion and pitting are the result of chemical action from the feed water, while grooving is a combination of chemical and mechanical action

General corrosion is hard to discover, because it acts uniformly over a large surface. Sometimes the rivet heads waste equally with the plates so that the damage done the plates is not noticeable. Uniform corrosion is the hardest to detect and is the most capricious. Water may attack the plates only at the water line. In some instances the damage is confined to a belt six or eight inches wide at the water level. Sometimes a few rivets or a part of the seams may be corroded, the rest remaining intact. Stays are often weakened more rapidly than boiler plates. The threads of screw stays may be badly corroded and the turned surfaces untouched. The capricious action depends upon the specific gravity of the corrosive agents, the difference of temperature, the difference of structure of the iron, etc. The best way to measure the amount of wasting is to drill the plates. If the thickness of the plates is found to be considerably reduced, the working pressure should be proportionately lowered.

Pitting is clearly defined by the edges of the pits or holes. From this appearance both the extent and depth are well marked. Pitting appears in the form of small holes or patches from ½ inch to 12 inches in diameter, or often as irregular shaped depressions. If the holes are small and close together, the plate is said to be honeycombed. The reason why plates become pitted instead of uniformly corroded has not been satisfactorily explained. It is generally believed to be the lack of homogeneity. Galvanic action between the iron plates and the copper or brass tubes is another claim for the cause, but as pitting occurs when there is no copper or brass near the plates, this theory breaks down.

The phenomenon of pitting is satisfactorily explained as the result of simple chemical action. Acids attack the most susceptible portions of the plate. The corrosion of firebox plates is often considered the result of galvanic action, but there is no doubt that the injury done to plates by drilling and punching is to some extent responsible.

The cause for **grooving**, channeling or furrowing, is not always apparent. It usually is due to the straining, springing, or buckling of the plates, aided by local corrosion. The straining of the plates may be due to insufficient or improper staying, thus causing the plates to spring back and forth as the steam pressure varies. This is most commonly found in stationary boilers of the Cornish and Lancashire types. It appears on the flat end plates around the edge of the angle iron, or in the root of the angle iron. Too rigid staying of the ends by gusset or diagonal stays, or too great a difference in expansion of the tubes and shell is almost sure to cause grooving. Grooving may be due either to excess or to lack of stiffness. Grooving often occurs at the transverse joints when the riveting has not been properly done. Internal grooving is a direct result of excessive calking, which by injuring the surface of the metal, exposes it to the corrosive action of the feed water. When the feed water causes a thick layer of scale, if unequal expansion cracks it and exposes a fresh surface to corrosive action, grooving is likely to appear.

Sometimes grooving is so fine as to appear to be a crack or fracture. If the crack is only $\frac{1}{64}$ of an inch wide, it may extend into the plate for a considerable depth. On account of the minuteness of the cracks, they are likely to escape detection and when once formed, rapidly enlarge from any acidity in the feed water.

The best way to prevent internal corrosion is to use water which has no corrosive effect on the plates. If internal corrosion has begun, a change of water will often prolong the life of the boiler. In some instances it is cheaper to build a new boiler every few years than to use a different water supply. This is not always best, for there is a tendency to use the boiler as long as possible, even after it has become unsafe. Sometimes the introduction of a thicker plate at places where the water is found to effect them will be economical; but as these plates will be stronger the strain will not be uniform. Another method is to neutralize the acidity of the feed water by some alkaline substance. This is done by dissolving soda or soda-ash in the feed water before it enters the boiler. The amount of soda to be used varies with the amount of acid. If there is considerable salt in the water, the introduction of soda is injurious.

Incrustation. The hard scale formed by the accumulation of the deposit of sediment from the feed water is sometimes called **scurf, fur,** or **incrustation.** The solid matter of the feed water is precipitated by the rise of temperature, or is left behind by evaporation. These solids, unless blown out, become hardened and form scale.

The amount of solid matter in solution is measured in **grains per gallon;** usually 20 to 40 grains per gallon. The quantity varies considerably. It is not the amount but the nature of the solids that determines the fitness of feed water. With proper attention to blowing off, the presence of a certain amount of carbonate, or chloride of soda would not be injurious, while the same number of grains per gallon of salts of lime would cause much trouble. **Salts of lime** are the ones most frequently found. The chief troublesome impurities found in feed waters for land boilers are sulphate and carbonate of lime, carbonate of magnesia, and some organic impurities. Marble and limestone are other names for carbonate of lime.

Water may be divided into two classes; **hard** and **soft.** Hard waters contain considerable lime, while soft waters have but little solid matter in solution.

The **carbonates of lime** and magnesia are held in solution in water by an excess of carbon dioxide. Heating the water will drive off the excess of carbon dioxide, or carbonic acid, and most of the carbonates will be precipitated. The precipitate is a whitish or grayish mud. As the temperature **increases,** the solubility **decreases,** and at the boiling point it is scarcely soluble. If the carbonates are not mixed with impurities, they may be washed out of the boiler after it has been allowed to cool. But if there is oil, organic matter, or sulphate of lime with them, the deposits are likely to become hard.

Sulphate of lime, like the carbonate is precipitated when the temperature rises. If water containing sulphate of lime, which forms a hard adhering scale, is heated to 280°F. all the lime will be precipitated. If a little carbonate of soda or soda-ash is introduced with the feed water, calcium carbonate is precipitated in the form of a fine white powder which may be washed out. The amount of carbonate of soda to be used may be calculated if the mineral impurities of the water are known. The soda should be introduced at regular intervals. The measured or weighed portion is dissolved in the water and then pumped into the boiler. An excess of soda is likely to cause foaming, and often sticks in the water glass. These indications show too much soda, but do not indicate when the right amount is being used.

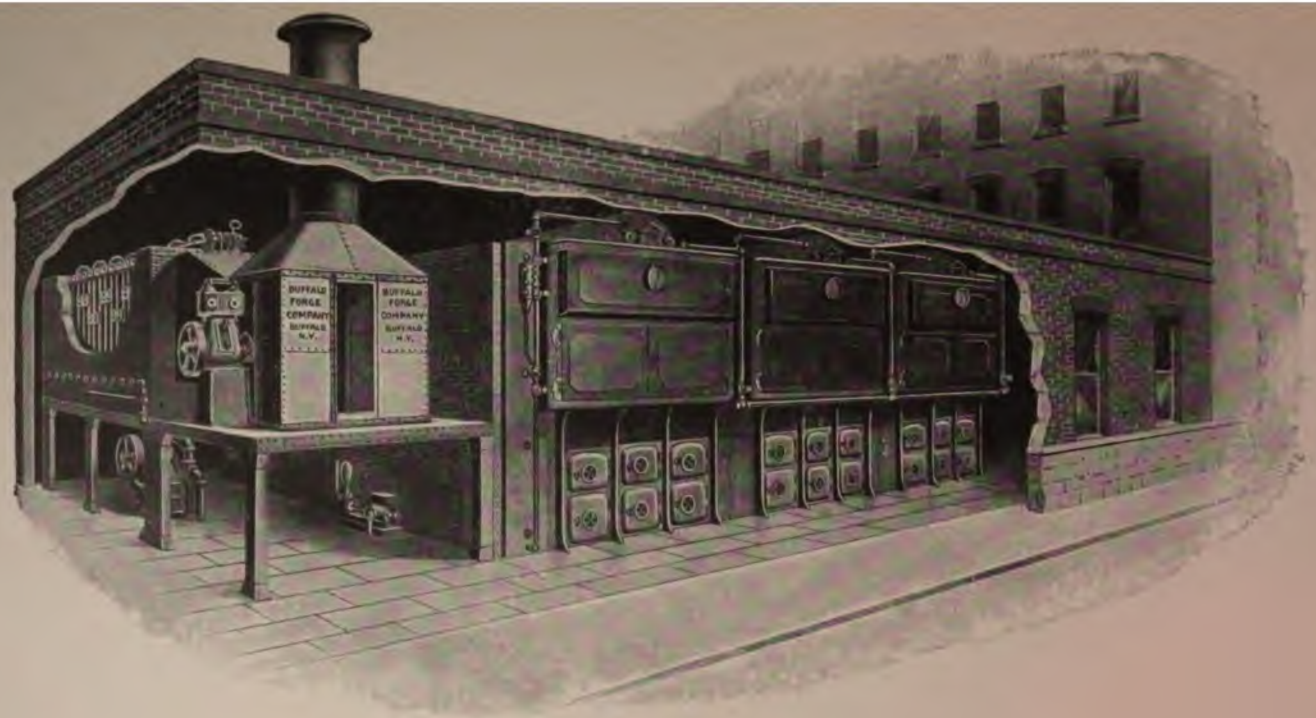
Sulphate of lime forms an amorphous crust, or scale. The hardness depends upon the other impurities and the temperature. If water that contains lime, forms a hard scale, sulphates are present, and the amount of soda to be used may be determined by trial. The deposits of the carbonate of lime are soft and granular, and of grayish color. Sulphate of lime forms a hard crust. Ammonium chloride, commonly called sal-ammoniac, is sometimes used to break up the lime compounds but is not always desirable as it does not act on the sulphate and may break up the chlorides, thus forming free chlorine which attacks the boiler.

Carbonate of magnesia is seldom found in as large quantities as the salts of lime. It is like carbonate of lime in solubility.

When the feed water contains iron salts the incrustation is of a reddish color. Water containing these salts is generally very injurious to the boiler plates. Brackish water containing chloride of magnesia is also injurious, for when heated, the chloride decomposes, forming magnesia and hydrochloric acid which rapidly corrodes iron.

A piece of thick scale broken from the plates of a boiler, shows a series of layers of varying thicknesses. Some of them may be crystalline and some amorphous. Between these hard layers are sometimes found layers of soft or earthy matter.

The oil used in the engine is likely to get into the boiler if a surface condenser is used. If the feed water has a little organic matter or lime salts in it, the effect of the oil is increased. The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deposit of oil mixed with other impurities is a poor conductor of heat and the resultant overheating of the plate often causes bulging, as shown in Fig. 62.

A very thin coating of scale is generally regarded as beneficial rather than harmful, because it protects the plates from the corrosive action of the water. A thick scale however, reduces the conducting power of the plates, scale being a poor conductor of heat. A thick coating is not only uneconomical, but is dangerous since the heat from the furnace may burn the plates instead of being conducted to the water.

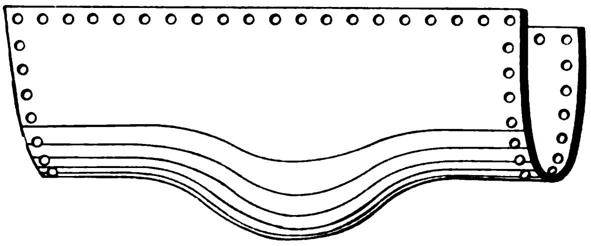

Fig 62.

In regard to the loss of heat caused by scale on the heating surface, nothing is definitely known. There are too many circumstances to be considered to admit of exact calculation. It is stated that a layer $\frac{1}{16}$ of an inch on the tubes of multitubular boilers is equivalent to a loss of 15 to 20 per cent. of fuel, and the loss increases rapidly with the thickness. Also that when $\frac{1}{4}$ of an inch thick, 60 per cent. more fuel is required, and when $\frac{1}{2}$ inch thick, 150 per cent. The above statements indicate the loss by incrustation, but the figures cannot be relied upon, because neither the kind of boiler, nor the kind of incrustation is stated. Some boilers would work very well with $\frac{1}{2}$ an inch scale on the furnace plates while others would not work at all. Boilers have been worked with scale $\frac{1}{2}$ inch thick without a loss of even 100 per cent. of fuel. A uniform coating is not nearly as harmful as irregular deposits. The deposit that produces the effects of overheating where it is least suspected is a powder composed chiefly of carbonates of lime and magnesia. As it is very light, it does not sink to the plates, but is held in suspension or covers the surface as a scum. If this powder becomes mixed with oil or grease the resistance offered to the rise of bubbles of steam is considerable. A layer of steam may thus be formed above the plates and the water lifted from them. As steam is a poor conductor of heat, the plates are likely to become overheated.

A compact homogeneous mass like hard scale is less harmful than a spongy powdery mass. This is readily seen from the fact that clean water can be boiled in a tea kettle having scale $\frac{1}{4}$ inch thick, with less danger of burning than can milk or water thickened with flour or oat-meal in a clean vessel. Loose sand is not as good a conductor of heat as solid rock.

Incrustation may be prevented, *1.* By precipitating the scale-forming substances before the feed water enters the boiler; *2.* By removing the sediment before it becomes hard scale, and *3.* By removing the hard scale from the interior of the boiler.

Water may be purified to a considerable extent by passing it through a purifier before allowing it to enter the boiler. The carbonate and sulphate are precipitated by heat. If the water contains much organic matter, it is advisable to filter it.

The precipitation of scale formation and the neutralization of acids in the feed water are accomplished to a greater or less extent by various chemicals. Soda, either as carbonate, soda-ash, or caustic soda is perhaps the most common. When soda and sulphate of lime are mixed, they exchange their acids and form sulphate of soda, which is soluble, and carbonate of lime which is precipitated. The action on the carbonate of lime is the precipitation of the lime salts. Caustic soda if concentrated may have a corrosive action. It should be used in smaller quantities than common soda. Potash, chloride of barium and tannic acid are also used, but soda is the most common. When tannic acid is used its action should be closely watched.

After the impurities are deposited in a boiler, the easiest way to remove them is by the **blow-out apparatus.** Impurities are held in suspension and float at the top of the water for considerable time before settling; the surface blow-out is used in this case.

It is sometimes stated that the loss by frequent blowing off is greater than that caused by scale. The loss of heat occasioned by blowing out a large quantity of water is considerable and whether or not it is advantageous to do so depends upon the particular case.

If lime and magnesia salts are to be blown out, the blow-out taps should be opened frequently; about every hour.

A rapid **circulation** of the water prevents the formation of scale. The sediment is swept through the tubes and shell until it enters the mud drum or is blown off. This is one of the chief advantages claimed for water tube boilers.

The suspension of blocks of wood, sheet iron, zinc, etc., to catch the deposits is sometimes beneficial.

Zinc is used to a considerable extent to prevent corrosion and incrustation. When zinc is placed in connection with the plates, galvanic action is set up which destroys whatever action there may have been between the plates and fittings, or between the different portions of the plates. It is also claimed that the galvanic action prevents the formation of scale by liberating hydrogen at the exposed surfaces.

When incrustation is once formed there are several methods for removing it. It may be chipped off carefully with suitable tools: this operation is safe but laborious. This method is difficult if the boiler is complicated, or if the scale adheres closely. If the chipping is not carefully done, the surface of the plates and the rivet heads may be injured. If the surface of the iron is broken, the next formation of scale will cling more closely and any corrosive agent in the feed water will have a better opportunity for attack.

Another method of removing the scale is by sudden expansion and contraction of the plates. This is accomplished by blowing off, then admitting a large volume of cold water, or by cooling down as quickly as possible after the fire is drawn. These processes will generally remove the scale in large pieces, or loosen it so that it can be easily removed; but they are very harmful to the boiler and have led to destruction of boilers and loss of life.

The **simplest** method is to allow the boiler to cool as gradually as possible and then stand full of cold water for a few days The deposits are thus prevented from being baked hard on the plates and the sulphate of lime has an opportunity of re-dissolving in the cold water. On emptying the boiler the sulphate of lime is removed with the water and the deposits are washed or brushed out.

Kerosene oil is used to a considerable extent to prevent and remove scale. It breaks up and loosens hard scale and also prevents its formation. It is claimed that one quart per day for a 100 horse-power boiler is sufficient.

The following table gives a brief review of common corrosion, incrustation, causes and remedies:

TROUBLE.	CAUSE.	REMEDY.
Corrosion.	Chloride and Sulphate of Magnesium.	Carbonate of soda.
	Acids.	Alkalies.
	Grease.	Carbonate of soda. Filter. Use mineral oil.
	Carbonic acid and Oxygen	Heat feed water. Soda or slacked lime.
	Organic matter.	Precipitate with alum and filter.
Incrustation.	Sulphate of lime.	Carbonate of soda.
	Carbonates of lime, Magnesium and Iron.	Heat feed water. Soda, lime, or magnesia.
	Sediment, mud, etc.	Blow off, or filter.
	Any soluble salts.	Blow off.
		In general, kerosene, chipping, etc.
Priming.	Organic matter.	Precipitate with alum and filter.

Fractures. There are two classes of fractures. *1.* Those caused by lack of freedom for expansion and contraction. *2.* Those caused by inability of the material to bear the steam pressure.

In an internally fired boiler, the internal flue may expand considerably, while the shell, held by stays and the ends, will expand but little. When the fire is external, *i. e.*, under one end, the plates just above the fire being very hot expand more than the rest of the shell or the tubes. If the tube plates cannot expand and contract, the tube holes are likely to become oval and leak. Furnace plates fracture from sudden contraction caused by cooling of the plates when the furnace door is opened.

Plates usually fracture from the holes to the edge of the plate in the outside lap. Fractûres are not always dangerous, but do need repairing. Usually they are small and at first barely visible, but soon they enlarge and when increased by corrosion cause leakage and perhaps rupture. When the lap-edge fractures extend through the rivet holes into the plate, drilling holes and placing rivets in their path will usually stop them. When the fractures run in a line between the rivet holes, they are dangerous. A good plate will usually leak and give indication of danger, while a brittle plate gives way suddenly. Thick plates are more likely to fracture than thin plates.

Bad workmanship and brittle plates are common causes for fractures. Careful supervision and the employment of skilled workmen are the only remedies for this evil. In case a plate is punched at the wrong points and then punched over again it is greatly weakened. This defect is often concealed by an angle iron.

Sometimes a boiler will rupture immediately after repairs. The plates are often injured by the methods used to knock off the rivet heads and force out the old rivets. When the new plates are put on, the reckless use of the drift increases the injury.

BOILER EXPLOSIONS.

The first requisite of a steam boiler is **safety**. This condition is not always fulfilled, but the frequent disastrous explosions prove its necessity. When a boiler explodes, the first question asked is, "*What caused it?*" Answers differ widely, and sometimes the cause is unknown. Those interested are often unwilling that there should be an investigation, thinking the responsibility may be placed on them.

Since the explosion of a boiler in a city is likely to prove fatal to many people, and cause much destruction, the responsibility of the boiler owner is not slight. The owner should be held liable in case of explosion, if he uses a boiler of poor type, a boiler which is not regularly inspected, a condemned boiler, or if he employs a man to take charge of it who holds no license.

The damage done by explosion is due to the energy stored in the hot water. The amount of energy in hot water is calculated by thermodynamic methods. The energy in one pound of hot water at 150 pounds pressure and 358°F., is about 10,500 foot pounds, *i. e.*, it is sufficient to raise one pound to a height of nearly two miles, and if at 250 pounds pressure, it has sufficient energy to raise it nearly three miles.

Energy. The energy stored in a Lancashire boiler 30 feet long and 8 feet in diameter, with 150 pounds pressure, has been calculated to be about 207,600 foot-tons, which is sufficient to raise the whole boiler 12,500 feet, or more than two miles. It takes 1,730 pounds of gun-powder to give an equivalent energy. The energy in a marine boiler 15 feet long, 13 feet in diameter and with a pressure of 150 pounds, is equal to 2,464 pounds of gun-powder. An ordinary return tubular boiler under 75 pounds pressure, has within it sufficient energy to blow it over a mile into the air. The above figures give some idea of the enormous amount of energy in a boiler, and the destruction caused by its explosion.

If a boiler filled with steam and hot water, fractures, or the pressure becomes more than the plates can withstand, a violent explosion generally follows. The steam escaping through the rent, or opening, diminishes the pressure slightly, thus causing a large quantity of steam to be generated from the hot water in a very short time. The instantaneous formation of a large quantity of steam produces disastrous results. The larger the body of hot water, the greater the disaster on account of the stored energy, sometimes called thermal storage. This fact accounts for the safety of water tube boilers; the division of the water into small masses in the sections prevents violent explosion. The bursting of one of these sections is unusual, but in case it happens the damage rarely extends beyond the boiler room; sometimes it merely causes a rush of steam into the room. This is disagreeable but not fatal. The explosion of a shell boiler usually wrecks the whole building. A small part of the stored energy is used in smashing up the boiler; the larger part scatters the fragments.

Causes. The general cause for boiler explosions is over pressure of steam. This over pressure is due to the inability of the boiler to stand the working pressure, or to the failure of the safety valve to blow off at the required pressure.

The reasons why a boiler is unable to bear the working pressure are: *1.* Defective design, or ignorance as to the amount of pressure the boiler will stand. *2.* Deterioration, that is, reduction of strength from corrosion, incrustation, and wear. *3.* Defective workmanship or material. *4.* Mismanagement.

Defective Design includes the following faults. The boiler may be insufficiently or improperly stayed; the stays being too small or too few, or they may be bent or cut to clear floats, pipes, etc. Flat surfaces may be stiffened but not stayed. The internal furnace flues may not have sufficient strengthening rings. The large holes for manholes, domes, etc., may be cut in the plates without the edges being properly strengthened. The boiler may be set too rigidly and no provisions made for expansion and contraction of the plates. Defective water circulation causes overheating, excessive incrustation, etc. The feed apparatus, not being in good working order, causes low water, overheating, rupture, and explosion. A badly designed safety valve may cause considerable trouble if not disaster.

Deterioration. The strength of a boiler may be impaired by fractures, general corrosion, pitting, or grooving. External corrosion especially, is the cause of many disasters. It can proceed unseen in many cases and rupture may occur when least expected. In the investigation of boiler explosions, the plates have often been found much reduced in thickness. When incrustation and grease have formed a pocket as previously explained, neglect to repair will usually result in rupture or explosion. The admission of cold feed water on hot plates is likely to cause fractures, which enlarge by fluctuation of pressure and corrosion until the boiler becomes too weak to bear the steam pressure.

Vertical boilers are the most likely to explode. The upper ends of the tubes, if they pass through the steam space, by collapsing, will cause disaster. The crown sheet is likely to corrode and bulge downward; the reaction of the escaping steam may throw the boiler high in the air.

The strength of a boiler, originally sufficient to stand high pressure, may become suddenly reduced by over-heating or over-straining. *Over-heating* makes the plates soft and weak. It may be caused by lack of water, accumulation of sediment or scale on the furnace plates or flues, defective circulation, or the concentration of heat on thick plates. *Over-straining* is caused by cooling and contraction, or by sudden expansion of tubes or flues.

Shortness of water, or low water, is the result of leakage of joints, valves, taps, etc., or of neglect to close the valves. It is also caused by sudden demand for steam, failure of the feed supply or check valve, the water siphoned from one boiler into another, defective gages, etc.

Defects of workmanship and material are usually found in flue boilers. They can be readily examined inside, and also subjected to the hydraulic test. Defects of workmanship are: careless punching and riveting, fractured rivet holes, broken rivets, carelessly secured stays, fractures in flanging, bending, welding, hammering, etc. Patching old plates with new ones, seriously damages them, especially if the removal of the old rivets and the placing of the new ones is not carefully done. The greater contraction and expansion of the new plate causes a severe local strain.

Defects of material are not easily discovered. Ordinary inspection will not reveal brittleness. Blisters, laminations, and adhesion of foreign substances during manufacture are usually detected during inspection.

Mismanagement causes many explosions. The pressure in a steam boiler may rise above the blowing off pressure by rusting of the safety valve, by poor design, by intentional or accidental overloading of the safety valve, by placing it on the steam pipe, or by placing a stop valve between the boiler and the safety valve. In one instance a safety valve, recovered from an explosion was corroded to such an extent that 3,000 pounds pressure was required to start it from its seat. When the size or lift of the safety valve is small, steam may be generated faster than it can escape, and cause a rapid increase of pressure. The lever safety valve is easily overloaded, either by an increase in length or by an addition of weights. It also may be wedged down. The safety valve is sometimes overloaded to make the blow off pressure equal the pressure indicated by a defective pressure gage. It is often loaded or wedged down to prevent leakage at the working pressure, in case it needs regrinding. The sudden opening or closing of a large steam or safety valve may convert static pressure into dynamic force, which may produce a violent rush of steam and hot water against some part of the boiler. This pressure may be enormous, causing rupture and perhaps explosion.

The practice of placing a stop valve between the boiler and the safety valve cannot be condemned too strongly. During repairs the stop valve may be shut and the communication temporarily shut off. Neglect to open the valve on resuming steam pressure is likely to cause serious trouble.

It is a common idea that when the furnace plates become very hot, heated to redness for instance, and the feed turned on, a violent explosion is sure to follow. Experiment shows that when a piece of wrought iron is heated to redness and plunged into a weight of cold water, three or four times greater than that of the iron, a very small quantity of steam is disengaged. Why should the quantity of steam be greater if the iron is in the form of a boiler? If a boiler contains considerable hot water, heated to 400°F. for instance, the addition of cold water might be followed by an explosion. If the body of water admitted to hot plates is small, there is greater danger of disaster.

The following experiments illustrate the action of cold water on hot plates. A boiler 25 feet long and 6 feet in diameter was heated red hot and the feed turned on. No explosion occurred; but the sudden contraction of the overheated plates caused the water to pour out in streams at every seam and rivet hole as far as the fire mark extended. In another instance, the water was almost entirely drawn off while the fires were burning briskly. When the remaining water had been converted into steam and all the fusible plugs melted out, water at the rate of 28 gallons per minute in a series of fine jets was played on the hot plates. The only effect was to reduce the pressure.

That a tough paper or cloth is easily torn when once started is a well-known fact. Similarly a boiler plate may be ruptured at slight pressure if the fracture has been started.

The **position of the fracture** or hole has a great influence on the results. In case a large rent occurs at the top of a cylindrical boiler, the steam and hot water may blow out of the hole, and the boiler, if strongly enough seated to stand the recoil will remain on its seat. The damage to the boiler would be slight. But suppose the same rent were situated on the under side of the boiler near the ground or floor; the effect would be very different, the reaction of the escaping steam would probably blow the whole boiler through the roof.

Investigation. When an explosion occurs it should be **investigated**; not only to fix the responsibility where it belongs, but also to provide for and take means to prevent future disasters. It has been customary to attribute all explosions to low water, since it is an easy way to throw the responsibility from the makers or owners upon the fireman, who, even if living, cannot defend himself. In the investigation of an explosion the weights, shapes, positions, and directions of the scattered pieces should be noted, so that their original places may be known. The original size and shape of the boiler and of the fittings should be known as accurately as possible. The primary rent may be discovered from comparison and from deductions of the directions taken by the heavier pieces. Light pieces will generally take the direction of the escaping steam, while the heavy parts take an opposite direction, that of the reaction. A careful examination of the pieces, noting the age of fractures, thickness of plates, amount of corrosion, condition of plates, etc., will generally show the cause. A test of the plates will in many cases show any softening or yielding to the pressure and excessive thinness caused by bulging.

Prevention. The means taken to prevent boiler explosions from most of the above mentioned causes have been already given. It is of primary importance that at the start only a well-designed and well-made boiler should be used. The matter of type is not of so much importance, but it is well to use a sectional boiler in large cities or in buildings where many people are employed. There are many methods, some of which have been discussed, that are taken to prevent deterioration by corrosion, fracture, etc. Proper setting is of great importance in this matter. Mishaps from mismanagement may be greatly lessened by the employment of licensed attendants. A boiler should *never* be in the hands of a man who is not thoroughly competent to run it. The most effective method to prevent explosions is the law of the state, compelling regular, thorough inspection and licensed firemen. The inspection by the Boiler Insurance companies is also an efficient method.

During a period of eleven and one-half years 70,000 boilers were inspected by Boiler Insurance companies. It was estimated that there were 140,000 in use during that time. Of the inspected boilers, there were 23 explosions and 50 collapses; resulting in 27 deaths from explosions, and 28 deaths from collapses. The explosion rate was 1 in 11,000 and the death rate 1 in 14,600. The uninsured boilers did not make as good showing; the death rate being 1 in 5,000 boilers, or about 3 times as high as among the insured boilers.

FUELS.

Coal is the most important fuel and in many localities the *only* one. As the population increases and the demand for timber increases, the use of wood as fuel for boiler furnaces diminishes. In some places wood, gases, and oils are abundant, and therefore most used. For some manufacturing plants, the waste products, such as straw, tan, sawdust and bagasse are the most economical.

There are several kinds of coal, all of vegetable origin, but differing according to the geological changes in the locality in which they are found.

There are five chief kinds of coal;

1. **Anthracite,** a hard variety, consisting almost entirely of free carbon.
2. **Dry bituminous,** having 70 to 80 per cent. of carbon.
3. **Caking bituminous,** having 50 to 60 per cent. of carbon.
4. **Cannel coal,** having 70 to 85 per cent. of carbon.
5. **Lignite,** or brown coal, containing 56 to 76 per cent. of carbon.

Anthracite Coal consists almost entirely of carbon and has but little hydrocarbon. Good anthracite is hard, lustrous, compact, and breaks up easily under a high temperature. It burns with very little flame and smoke, unless wet, and gives an intense heat. On account of its brittleness, the fine pieces will be lost unless the spaces in the grate are small, or a down draft furnace having double grates, is used.

A variety of coal called semi-anthracite or semi-bituminous, which contains some hydrocarbon, is not as compact as good anthracite and burns with a short flame. Anthracite coals are found chiefly in the Allegheny Mountains and in the Rocky Mountains of Colorado.

Bituminous Coal contains a large and varying amount of hydrocarbon, or bituminous matter.

Dry bituminous coal burns freely, with little smoke and without caking. It is found in Maryland and Virginia.

Caking bituminous becomes pasty, swells up and cakes when burning. It is used for making illuminating gas, and is mined principally in the Mississippi Valley.

Cannel Coal, or long flaming bituminous, has a tendency to produce smoke; some varieties cake. Cannel coals are found in Pennsylvania, Indiana, and Missouri.

Lignite, or brown coal, is intermediate between coal and peat. It is made up mostly of carbon, with some moisture and mineral matter. Poor varieties are of little value. Lignites come from Colorado, Texas, and Washington.

There are a few solid fuels which are of importance, although they are but little used as a boiler fuel.

Coke is made by driving off, by heat, the hydrocarbon of bituminous and semi-bituminous coals. If made in gas retorts, it is weak, and is but little used for making steam. When made in coking ovens, it is dark gray, hard, porous, and brittle. It gives out a slight ringing sound when struck, and has a metallic lustre. If the coal is moist, or if steam is used in coking, as in the manufacture of water gas, the sulphur is burned out. Coke burns without flame, and will, if forced, make a hot fire.

Charcoal. Charcoal is seldom used in the steam boiler furnace. It is made by evaporating the volatile constituents of wood, either by partial combustion or by heating in retorts. If it is made in conical heaps, 100 parts of wood by weight, yield about

20 parts of charcoal; if made in retorts about 30 parts of charcoal are realized. About 50 bushels of charcoal are obtained from a cord of wood.

Peat. Peat, or turf, consists of decayed roots and earthy matter. It is found in bogs and swamps. After it is cut out and dried, it is sometimes pulverized and compressed as an artificial fuel. The amount of ash is from 5 to 11 per cent. Its specific gravity is from .4 to .5, but it can be compressed to greater density.

Wood. There are two principal divisions of wood. Hard wood, which is compact and comparatively heavy, as oak, ash, etc., and soft wood, which is light colored, soft, and of less specific gravity than hard woods. Pine, birch, and poplar are examples of soft woods. Wood contains considerable moisture, even if left in a dry place for a few years. After being thoroughly dried, it will absorb and retain from ten to twenty per cent. of moisture. The chemical composition of different woods is nearly alike and is about as follows:

	Perfectly Dry Wood.	Ordinary Fire Wood.
Carbon	50 per cent.	37.50 per cent.
Hydrogen	6 "	4.50 "
Oxygen	41 "	30.75 "
Nitrogen	1 "	.75 "
Ash	2 "	1.50 "
Moisture	. . . . .	25.00 "

English oak, a hard wood, has a specific gravity of .93 and weighs 58 pounds per solid cubic foot. Yellow pine, a soft wood, weighs 41 pounds per solid cubic foot. Its specific gravity is .66.

A cord of wood measures 4 feet by 4 feet by 8 feet and equals 128 cubic feet. For ordinary pine wood, one cord weighs 2,700 pounds, or 21 pounds per cubic foot.

The heating value for a given weight of different kinds of wood is very nearly the same. That is, one pound of hickory is worth no more as fuel than one pound of pine, if both are dry. Wood that is kiln dried has a theoretical heat value of almost 8,000 B. T. U., while wood containing about 25 per cent. moisture has a value of about 6,000 B. T. U.

The most important elements in coal are hydrogen, producing 62,000 B. T. U. per pound, and carbon, producing 14,500 B. T. U.

per pound. Although several coals may have the same total percentage of combustible and ash, the heat values may not be the same, because heat value depends upon the amounts of hydrogen and carbon they contain. The heat value of fuels is determined by chemical analysis, or by calorimetric test, and varies for coal from different localities. The following table is compiled from several sources.

Kind of Coal.	Per cent. of ash.	Theoretical B. T. U. per pound.	Pounds of water evaporated per pound. (Theoretical.)
Penn. Anthracite	3.49	14,199	14.70
Penn. Anthracite	2.90	14,221	14.72
Penn. Cannel	15.02	13,143	13.60
Penn. Connellsville	6.50	13,368	13.84
Penn. Semi-bituminous	10.70	13,155	13.62
Penn. Brown	9.50	12,324	12.75
Kentucky Caking	2.75	14,391	14.89
Kentucky Cannel	2.00	15,198	16.76
Kentucky Lignite	7.00	9,326	9.65
Indiana Caking	5.66	14,146	14.64
Indiana Cannel	6.00	13,097	13.56
Maryland Cumberland	13.88	12,226	12.65
Arkansas Lignite	5.00	9,215	9.54
Colorado Lignite	9.25	13,562	14.04
Texas Lignite	4.50	12,962	13.41
Washington Lignite	3.40	11,551	11.96

In practice, no fuel gives its theoretical evaporation value on account of several losses. Heat is radiated from, and conducted away by the boiler setting. The admission of air into the furnace, either through the doors or through cracks in the setting, reduces the theoretical evaporation value. Improper firing, either by carelessness or ignorance, causes considerable loss, and errors in design, construction or of setting reduce the efficiency. The loss from radiation has often been found to be 20 per cent. A boiler seldom gives an efficiency of 80 per cent., the average being 65 to 70 per cent.

Tan. Bark after it has been used in the process cf tanning leather is called tan. This tan which is the fibrous part of the bark, is sometimes burned in the boiler furnace. The heating power of dry tan, containing 15 per cent. of ash, is about 6,000 B. T. U. If the tan is in the ordinary state of dryness, that is, containing 25 to 30 per cent. of moisture, the heat value is about 4,300 B. T. U. Perfectly dry tan will evaporate about 6.3 pounds of water supplied at 212°F. If the tan contains 30 per cent. of moisture, it will evaporate only 4.4 pounds.

Straw. Straw, in its ordinary condition, is composed as follows:

Carbon	36.	per cent.
Hydrogen	5.	"
Oxygen	38.	"
Nitrogen	.425	"
Ash	4.75	"
Water	15.75	"

The heat value for ordinary straw is about 7,000 B. T. U., equivalent to the evaporation of about 7.3 pounds of water from and at 212°F.

Bagasse is the fibrous portion of the sugar cane left after the juice has been extracted. It usually contains 25 to 40 per cent. of water. On account of the large amount of water, it must be dried before being used in the furnace. Bagasse is equal in calorific value to about one-fifth the same weight of coal. This value varies with the chemical composition. The larger the per cent. of extraction of the sugar, the drier the bagasse and the greater its evaporative power. It is therefore of great advantage to extract as much of the juice as possible.

Cook's automatic apparatus burns the bagasse direct from the sugar mill. This saves the labor of oxen and men required for gathering, spreading and firing. The amount of sugar, if the extraction is not complete, is sufficient, when used as a fuel, to evaporate the moisture. The combustion by this method is better than that obtained from any hand firing. The waste heat that escapes to the chimney is utilized in heating the air admitted to the furnace. This hot blast is very efficient when burning wet fuel.

Bagasse should be fed continuously into a very hot fire-brick chamber which has plenty of room to accommodate the large volume of gas and steam produced by the combustion.

Petroleum. Oil is now becoming a fuel of considerable importance. Petroleum is a hydrocarbon liquid composed of carbon, hydrogen and oxygen in slightly varying proportions.

The following is the composition of Petroleum.

Carbon	82 to 87 per cent.
Hydrogen	11 to 15 per cent.
Oxygen	.5 to 6 per cent.

The theoretical heating power is about 20,000 B. T. U. per pound, which is equivalent to the evaporation of 21 pounds of water from and at 212°F.

Petroleum oils are obtained from the distillation of petroleum and are compounds of carbon and hydrogen. The compounds varying from $C_{12}H_{24}$ to $C_{32}H_{64}$; or expressed in weight,

Carbon	from 71.42 to 73.77 per cent.
Hydrogen	from 26.23 to 28.58 per cent.

The specific gravity of petroleum is about .87 and that of the petroleum oils from .628 to .792. The heating value of petroleum oils is from 27,000 to 28,000 B. T. U., and the equivalent evaporation 24 to 25 pounds when water is supplied at 62°F., or 28 to 29 pounds when the water is at 212°F.

There are several advantages claimed for oil fuels, but there are also some disadvantages.

Advantages. A petroleum fire can be controlled by turning one valve. If the fire is regulated to produce the required heat. it can be kept at that point with very little care. The fire can be started with slight trouble and, if not wanted continuously, can be extinguished instantly. As in the case of the gas engine, there is no waste of fuel after the work is done.

Petroleum produces a uniform fire, much more so than that of coal or wood.

Coal contains about 14,300 heat units, of which about 8,000 are available, the rest being lost by incomplete combustion, radiation, etc. Petroleum, it is claimed, furnishes 20,000 B. T. U. and is equivalent to more than two pounds of coal.

A pound of *coal* in an ordinary boiler will evaporate from 7 to 11 pounds of water, while *oil tests* show 17 or 18 pounds.

Complete combustion, cleanliness and economy of labor are obtained by the use of petroleum.

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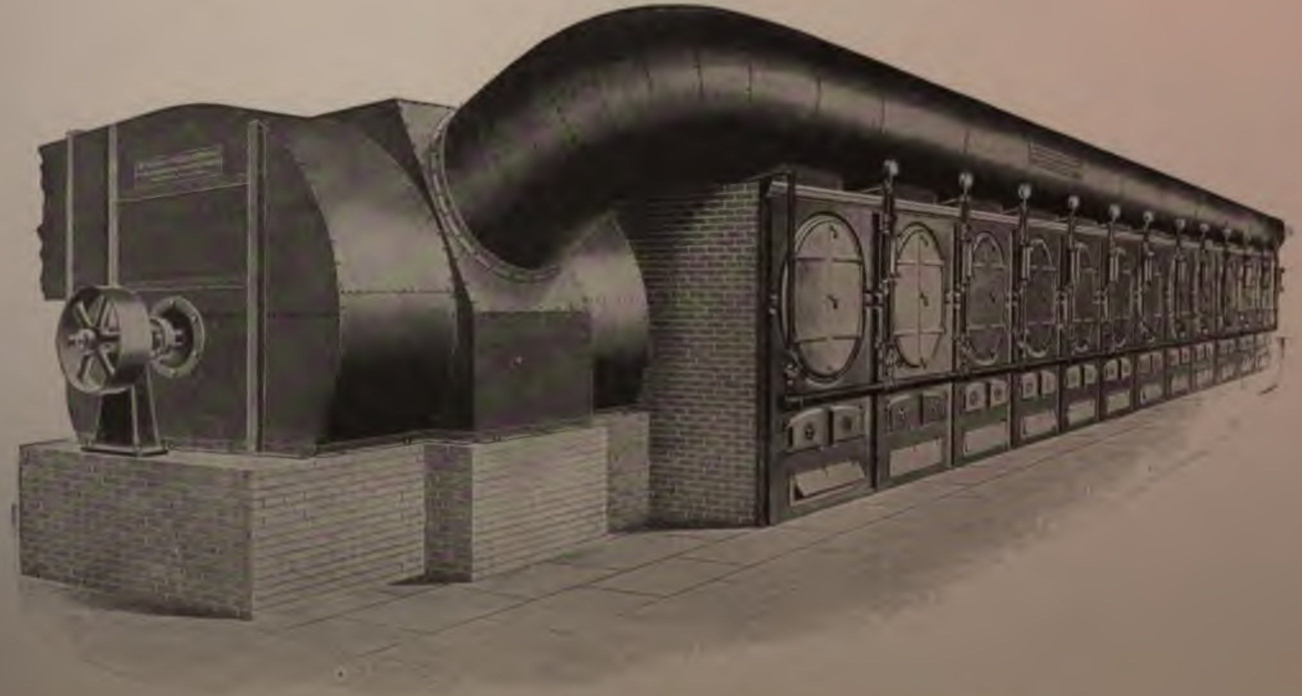


BOILERS EQUIPPED WITH DUPLEX THREE-QUARTER HOUSING FANS.
Induced Draft Plant at Watkins Salt Company.
Buffalo Forge Company.

The heat in the furnace does not fluctuate since there is no need of opening doors. The burning of petroleum is not as harmful to the furnace as the burning of coal, because the oil has less sulphur. The saving from handling is an important item, especially noticeable in marine work.

Among the **disadvantages** are: Danger from explosion on account of the vapors which rise from the fuel; loss of fuel by evaporation; unpleasant odor; comparatively high price.

The question of price of fuel is dependent upon locality, and must be determined for each case.

Mineral oil as crude petroleum, or the refuse heavy oil left from the distillation of petroleum oils is sometimes used as boiler fuel. The oil is thrown into the furnace as finely divided spray by means of special apparatus, in which superheated steam or compressed air is the motive force. Superheated steam is more convenient, but it is not as good on account of the inert material (moisture) to be heated.

Gas. Gas has many advantages over any other kind of fuel. Some think it an ideal fuel. Natural gas has been found in Pittsburg, Pennsylvania, and Indiana, in such quantities that many manufacturing industries use it exclusively. There have been many processes invented to produce artificial gas that would be cheap enough to compete with coal. Coal gas, made by the distillation of coal, and water gas, obtained by the decomposition of steam by incandescent carbon, have been used both for lighting and for fuel. In the following table of relative heat values, the water gas is not carbureted. When carbureted, its value may exceed that of coal gas. Producer gas is made by blowing steam and air through the coal.

	By weight.	By volume.
Natural gas	1000	1000
Coal gas	949	666
Water gas	292	292
Producer gas	76.5	130

The natural gas in the preceding table is from Findlay, O. The coal gas is an average sample used as an illuminating gas. The water gas is made for heating and not purified for illuminating. The producer gas is an average sample from the Pennsylvania Steel works, made from anthracite coal.

The value of natural gas is due to the large amount of marsh gas it contains, since the marsh gas has a large per cent. of hydrogen. On account of its large per cent. of hydrogen, coal gas is nearly equivalent to natural gas.

The relative values of these gases for evaporation are shown in the following table:

	Natural Gas.	Coal Gas.	Water Gas.	Producer Gas.
Cubic feet of gas	1000	1000	1000	1000
Pounds of water evaporation	893	591	262	115

Experiments in Pittsburg show that 1000 cubic feet of natural gas equals 80 to 133 pounds of coal. The coal used in the comparison varied from 12,000 to 13,000 B. T. U. per pound.

It has been stated by the Western Society of Engineers that one pound of good coal is equal to 7½ cubic feet of natural gas.

As in the case of petroleum, the economy of burning gaseous fuels depends upon the locality.

Artificial fuels. The waste of charcoal, coal, sawdust, etc., is often pressed into cakes, or briquettes, by means of some adhesive mixture with compression. Wood tar, coal tar and clay are used according to convenience. These cakes are compact, can be stored in a small space, and are used where good fuels are difficult to obtain.

TESTING STEAM BOILERS.

A steam boiler may be subjected to two tests, namely; the **strength**, and the **efficiency** test.

Even if the boiler has been carefully designed and the workmanship and every detail of construction carefully inspected, the safety can only be ascertained by the application of pressure. If every piece of metal has been tested and the parts put together according to best results of long experience, there may, however, be defects, such as bad welding, careless riveting, or plates cracked in flanging, which will greatly impair the strength of the boiler.

There are certain classes of boilers so constructed that it is almost impossible to inspect them from within; of which the locomotive, crane, and small agricultural boilers are examples.

Many hidden defects are brought to light by careful inspection and the pressure test.

There are two ways of applying the pressure test, by *steam* and by *water*. In testing by steam, the conditions of strain are the same as those under which the boiler is worked. But the practice of testing a boiler with twice the steam pressure that is required, is likely to weaken if not explode it.

One method of testing is to pump water into the boiler until the desired pressure is reached. The distortions or defects of joints are then noticed. In testing a new boiler, the various parts should be carefully measured and gaged, and the results recorded. After the test has been maintained for some time, the measurements should be taken again and compared with the original. Any extension or bulging should be noted. On release of pressure, the measurements should be taken a third time to find the permanent set of any part. In case of permanent set, the material should be carefully tested, to see whether the permanent set was due to defects of construction, or to an exceeded elastic limit. There are instances, stayed surfaces for example, when a slight permanent set does not render the boiler unfit for use.

If the boiler leaks under the hydraulic pressure, the leaky joints should be marked and calked when the pressure is off.

Another method is to fill the boiler with water, close every outlet and then build a fire in the furnace. Water expands $\frac{1}{24}$ of its volume when the temperature rises from 60° F. to 212° F. When the water in the boiler is heated there is a corresponding increase of internal pressure, and the condition of the boiler is judged from the movement of the pointer of the pressure gage. Steady rise of pressure indicates soundness, while jerks or starts of the pointer are considered to denote weakness. This method is seldom used because of the difficulty of regulating the fire so as to give a steady increase of heat and of keeping that heat constant for any length of time. Although no explosion can result from hydraulic tests, a serious accident can happen when the plates fracture. Many say that the hydraulic test is worthless because it does not show the actual strength. The most injurious stresses, those due to unequal expansion, are not set up during this test. In order to find out the exact strength, the boiler must be destroyed, or at least so fractured or strained as to become worthless.

The application of high pressure is likely to strain the boiler and to render it unfit for the intended low pressure.

A boiler that has been at work for some time is considered safe if it will stand the test of a pressure one and a half times the working pressure.

The inspection of a boiler should commence at the works where the plates are manufactured. If the material and each detail of construction is inspected and tested, the boiler is likely to be strong.

The other test; the efficiency test, is of importance to boiler owners in order that they may know the boiler from the economic standpoint.

STEAM BOILER TRIALS.

Object. The object of a boiler trial is to determine the following; the *quantity* and *quality* of steam it will supply under given conditions; the *horse-power* of the boiler and its *efficiency*; and the *amount of fuel* it takes to make the required steam.

The quantity of steam is taken as the amount of water evaporated. The quality is determined by some form of calorimeter, already described. The efficiency is the ratio of the heat units utilized in evaporating the water, to the total heat supplied to the boiler. The heat utilized in evaporation is calculated by multiplying the number of pounds of feed water by the number of heat units required to change water, at the temperature of the feed water into steam at the gage pressure. The heat units supplied are determined by weighing the fuel used during the test, and after deducting the amount of ash, multiplying the result by the total heat of combustion of the fuel. The heat of combustion is obtained either by calculation or by means of a fuel calorimeter.

Great care and skill must be exercised throughout the test, for slight errors in temperatures, pressures, weighings, etc., will make the results worthless. It is much better to use a throttling or separating calorimeter, because the inaccuracy of the barrel calorimeter is likely to make a large error in the final results.

The Committee of the American Society of Mechanical Engineers recommended the following code of rules for boiler trials.

PRELIMINARIES TO A TEST.

1. In preparing for and conducting trials of steam-boilers the specific object of the proposed trial should be clearly defined and steadily kept in view.

2. Measure and record the dimensions, position, etc., of grate and heating surfaces, flues, and chimneys, proportion of air-space in the grate-surface, kind of draught, natural or forced.

3. Put the boiler in good condition. Have heating surface clean inside and out, grate-bars and sides of furnace free from clinkers, dust, and ashes removed from back connections, leaks in masonry stopped, and all obstructions to draught removed. See that the damper will open to full extent, and that it may be closed when desired. Test for leaks in masonry by firing a little smoky fuel and immediately closing damper. The smoke will then escape through the leaks.

4. Have an understanding with the parties in whose interest the test is to be made as to the character of the coal to be used. The coal must be dry, or if wet, a sample must be dried carefully and a determination of the amount of moisture in the coal made, and the calculation of the results of the test corrected accordingly. Wherever possible, the test should be made with standard coal of a known quality. For that portion of the country east of the Alleghany Mountains good Anthracite egg coal or Cumberland semi-bituminous coal may be taken as the standard for making tests. West of the Alleghany Mountains and east of the Missouri River, Pittsburg lump coal may be used.

5. In all important tests a sample of coal should be selected for chemical analysis.

6. Establish the correctness of all apparatus used in the test for weighing and measuring. These are: *1.* Scales for weighing coal, ashes, and water. *2.* Tanks, or water-meters for measuring water. Water-meters, as a rule, should only be used as a check on other measurements. For accurate work the water should be weighed or measured in a tank. *3.* Thermometers and pyrometers for taking temperatures of air, steam, feed-water, waste gases, etc. *4.* Pressure-gauges, draft-gauges, etc.

7. Before beginning a test, the boiler and chimney should be thoroughly heated to their usual working temperature. If the boiler is new, it should be in continuous use at least a week before testing, so as to dry the mortar thoroughly and heat the walls.

8. Before beginning a test, the boiler and connections should be free from leaks, and all water connections, including blow and

extra feed-pipes, should be disconnected or stopped with blank flanges, except the particular pipe through which water is to be fed to the boiler during the trial. In locations where the reliability of the power is so important that an extra feed-pipe must be kept in position, and in general when for any other reason, water-pipes other than the feed-pipes cannot be disconnected, such pipes may be drilled so as to leave openings in their lower sides, which should be kept open throughout the test as a means of detecting leaks, or accidental or unauthorized opening of valves. During the test the blow-off pipe should remain exposed.

If an injector is used it must receive steam directly from the boiler being tested, and not from a steam-pipe or from any other boiler.

See that the steam pipe is so arranged that water of condensation cannot run back into the boiler. If the steam pipe has such an inclination that the water of condensation from any portion of the steam-pipe system may run back into the boiler, it must be trapped so as to prevent this water getting into the boiler without being measured.

STARTING AND STOPPING A TEST.

A test should last at least ten hours of continuous running, and twenty-four hours whenever practicable. The conditions of the boiler and furnace in all respects should be, as nearly as possible, the same at the end as at the beginning of the test. The steam pressure should be the same, the water-level the same, the fire upon the grates should be the same in quantity and condition, and the walls, flues, etc., should be of the same temperature. To secure as near an approximation to exact uniformity as possible in conditions of the fire and in temperatures of the walls and flues, the following method of starting and stopping a test should be adopted.

10. **Standard Method.** Steam being raised to the working pressure, remove rapidly all the fire from the grate, close the damper, clean the ash-pit, and as quickly as possible start a new fire with weighed wood and coal, noting the time of starting the test and the height of the water-level while the water is in a quiescent state, just before lighting the fire.

At the end of the test remove the whole fire, clean the grates and ash-pit, and note the water-level when the water is in a quiescent state; record the time of hauling the fire as the end of the test. The water-level should be as nearly as possible the same as at the beginning of the test. If it is not the same, a correction should be made by computation, and not by operating pump after test is completed. It will generally be necessary to regulate the discharge of steam from the boiler tested by means of the stop-valve for a time while fires are being hauled at the beginning and at the end of the test, in order to keep the steam-pressure in the boiler at those times up to the average during the test.

11. **Alternate Method.** Instead of the standard Method above described, the following may be employed where local conditions render it necessary.

At the regular time for slicing and cleaning fires have them burned rather low, as is usual before cleaning, and then thoroughly cleaned; note the amount of coal left on the grate as nearly as it can be estimated; note the pressure of steam and the height of the water-level—which should be at the medium height to be carried throughout the test—at the same time; and note this time as the time of starting the test. Fresh coal, which has been weighed, should now be fired. The ash-pits should be thoroughly cleaned at once after starting. Before the end of the test the fires should be burned low, just as before the start, and the fires cleaned in such a manner as to leave the same amount of fire, and in the same condition, on the grates as at the start. The water level and steam-pressure should be brought to the same point as at the start, and the time of the ending of the test should be noted just before fresh coal is fired.

DURING THE TEST.

12. **Keep the Conditions Uniform.** The boiler should be run continuously, without stopping for meal-times or for rise or fall of pressure of steam due to change of demand for steam. The draught being adjusted to the rate of evaporation or combustion desired before the test is begun, should be retained constant during the test by means of the damper.

If the boiler is not connected to the same steam-pipe with other boilers, an extra outlet for steam with valve in same should be provided, so that in case the pressure should rise to that at which the safety-valve is set, it may be reduced to the desired point by opening the extra outlet, without checking the fires.

If the boiler is connected to a main steam-pipe with other boilers, the safety-valve on the boiler being tested should be set a few pounds higher than those of the other boilers, so that in case of a rise in pressure the other boilers may blow off, and the pressure be reduced by closing their dampers, allowing the damper of the boiler being tested to remain open, and firing as usual.

All the conditions should be kept as nearly uniform as possible, such as force of draft, pressure of steam, and height of water. The time of cleaning the fires will depend upon the character of the fuel, the rapidity of combustion, and the kind of grates. When very good coal is used, and the combustion not too rapid, a ten-hour test may be run without any cleaning of the grates, other than just before the beginning and just before the end of the test. But in case the grates have to be cleaned during the test, the intervals between one cleaning and another should be uniform.

13. **Keeping the Records.** The coal should be weighed and delivered to the fireman in equal portions, each sufficient for about one hour's run, and a fresh portion should not be delivered until the previous one has all been fired. The time required to consume each portion should be noted, the time being recorded at the instant of firing the first of each new portion. It is desirable that at the same time the amount of water fed into the boiler should be accurately noted and recorded, including the height of the water in the boiler and the average pressure of steam and temperature of feed during the time. By thus recording the amount of water evaporated by successive portions of coal, the record of the test may be divided into several divisions, if desired, at the end of the test, to discover the degree of uniformity of combustion, evaporation, and economy at different stages of the test.

14. **Priming Tests.** In all tests in which accuracy of results is important, calorimeter tests should be made of the percentage of moisture in the steam, or of the degree of superheating. At least

ten such tests should be made during the trial of the boiler. or so many as to reduce the probable average error to less than one per cent., and the final records of the boiler test corrected according to the average results of the calorimeter tests.

On account of the difficulty of securing accuracy in these tests, the greatest care should be taken in the measurements of weights and temperatures. The thermometers should be accurate within a tenth of a degree, and the scales on which the water is weighed to within one hundredth of a pound.

Analysis of Gases.—Measurement of Air Supply, etc.

15. In tests for purposes of scientific research, in which the determination of all the variables entering into the test is desired, certain observations should be made which are in general not necessary in tests for commercial purposes. These are the measurement of the air-supply, the determination of its contained moisture, the measurement and analysis of the flue gases, the determination of the amount of heat lost by radiation, of the amount of infiltration of air through the setting, the direct determination by calorimeter experiments of the absolute heating value of the fuel, and (by condensation of all the steam made by the boiler) of the total heat imparted to the water.

The analysis of the flue-gases is an especially valuable method of determining the relative value of different methods of firing, or of different kinds of furnaces. In making these analyses great care should be taken to procure average samples—since the composition is likely to vary at different points of the flue, and the analyses should be intrusted only to a thoroughly competent chemist, who is provided with complete and accurate apparatus.

As the determinations of the other variables mentioned above are not likely to be undertaken except by engineers of high scientific attainments, and as apparatus for making them is likely to be improved in the course of scientific research, it is not deemed advisable to include in this code any specific directions for making them.

RECORD OF THE TEST.

A "log" of the test should be kept on properly prepared blanks containing headings as follows:

TABLE NO. 58.

Time.	Pressures.			Temperatures.					Fuel.		Feed-Water.	
	Barometer.	Steam gauge.	Draft-gauge.	External air.	Boiler room.	Flue.	Feed-water.	Steam.	Time.	Pounds.	Time.	Lbs. or cu. ft.

REPORTING THE TRIAL.

The final results should be recorded upon a properly prepared blank, and should include as many of the following items as are adapted for the specific object for which the trial is made. The items marked with a * may be omitted for ordinary trials, but are desirable for comparison with similar data from other sources.

Results of the trials of a..

Boiler at.................................. ....

To determine.................................. ....

1. Date of trial..			
2. Duration of trial..	hours.		
DIMENSIONS AND PROPORTIONS.			
(Leave space for complete description).			
3. Grate-surface ....wide.........long.........area.........	sq. ft.		
4. Water-heating surface..	sq. ft.		
5 Super-heating surface.	sq. ft.		
6. Ratio of water-heating surface to grate-surface............			
AVERAGE PRESSURES.			
7. Steam-pressure in boiler, by gauge............	lbs.		
*8. Absolute steam-pressure..	lbs.		
*9. Atmospheric pressure, per barometer........................	in.		
10. Force of draught in inches of water..................	in.		
AVERAGE TEMPERATURES.			
*11. Of external air	deg.		
*12. Of fire-room..	deg.		
*13. Of steam	deg.		
14. Of escaping gases..	deg.		
15. Of feed-water..	deg.		

	FUEL.			
16.	Total amount of coal consumed	lbs.		
17.	Moisture in coal	per cent.		
18.	Dry coal consumed	lbs.		
19.	Total refuse, dry.......pounds =	per cent.		
20.	Total combustible (dry weight of coal, item 18, less refuse, item 19)	lbs.		
*21.	Dry coal consumed per hour	lbs.		
*22.	Combustible consumed per hour	lbs		
	RESULTS OF CALORIMETRIC TESTS.			
23.	Quality of steam, dry steam being taken as unity			
24.	Percentage of moisture in steam	per cent.		
25.	Number of degrees superheated	deg.		
	WATER.			
26.	Total weight of water pumped into boiler and apparently evaporated	lbs.		
27.	Water actually evaporated, corrected for quality of steam.	lbs.		
28.	Equivalent water evaporated into dry steam from and at 212° F.	lbs.		
*29.	Equivalent total heat derived from fuel in B. T. U.	B. T. U.		
30.	Equivalent water evaporated into dry steam from and at 212° F. per hour	lbs.		
	ECONOMIC EVAPORATION.			
31.	Water actually evaporated per pound of dry coal, from actual pressure and temperature	lbs.		
32.	Equivalent water evaporated per pound of dry coal, from and at 212° F.	lbs.		
33.	Equivalent water evaporated per pound of combustible from and at 212° F.	lbs.		
	COMMERCIAL EVAPORATION.			
34.	Equivalent water evaporated per pound of dry coal with one-sixth refuse, at 70 lbs. gauge pressure, from temperature of 100° F. = item 33 × 0.7249 pounds	lbs.		
	RATE OF COMBUSTION.			
35.	Dry coal actually burned per square foot of grate surface per hour	lbs.		
*36.	Consumption of dry coal per hour. Coal assumed with one-sixth refuse. Per sq. ft. of grate surface	lbs.		
*37.	Per sq. ft. of water heating surface	lbs.		
*38.	Per sq. ft. of least area for draught	lbs.		
	RATE OF EVAPORATION.			
39.	Water evaporated from and at 212° F. per square foot of heating surface per hour	lbs.		
*40.	Water evaporated per hour from temperature of 100° F. into steam of 70 lbs. gauge pressure. Per sq. ft. of grate surface	lbs.		
*41.	Per sq. ft. of heating surface	lbs.		
*42.	Per sq. ft. of least area for draught.	lbs.		
	COMMERCIAL HORSE-POWER.			
43.	On basis of 30 lbs. of water per hour evaporated from temperature of 100° F. into steam of 70 lbs. gauge pressure (34½ lbs. from and at 212°)	H. P.		
44.	Horse-power, builders' rating, at.........square feet per horse-power	H. P.		
45.	Per cent. developed above, or below, rating	per cent.		

During the boiler trial the various observations (temperatures and pressures) should be made at the same time and at about fifteen minute intervals. In order to attain the result of the test the following must be known:

1. The amount in pounds, of coal burned and the number of pounds of ashes left.

2. The number of pounds of water pumped into the boiler.

3. The pressure of the steam in the boiler.

4. The temperature of the feed water when it enters the boiler.

5. The quality of the steam discharged from the boiler, that is, the per cent. of moisture in the steam.

There are several ways of determining the amount of water pumped into the boiler. The best method is to weigh it in tanks or barrels on scales, which have been adjusted and tested with a standard weight. The barrels or tanks should be two or more in number and of sufficient size so that the filling, weighing and emptying may not be hurried. The barrels should be placed high enough to discharge into the tank from which the feed water is drawn by the pump or injector. The valves should be large and quick opening so that the emptying will not be delayed.

If barrels are used they should be numbered and the weights of each accurately kept, and each weighed when empty and when full. When the water level in the tank has fallen so that it will hold another barrel of water, the barrel should be emptied into the tank and while emptying the other filled and weighed.

The weigher must use care and intelligence and must not become confused in his weighings or records. At the beginning of the test the level in the water tanks should be recorded, and at the end the level brought to the same mark.

If it is inconvenient to weigh the water, it may be measured either by a meter or by measurements in the tank. If a meter is used it should be tested and its error determined. The meter must be kept free from air or the readings will be in excess of the true ones.

The level in the water glass of the boiler should also be noted at the beginning and at the end of the test. A graduated scale attached to the gage glass is a convenient means of determining the water level.

The temperature of the feed water should be taken occasionally to get an average temperature.

If the boiler is fed by a steam pump, it should be run by steam taken from some other boiler if convenient; if not, the amount of steam used by the pump must be determined and allowance made.

The steam used by the pump may be condensed and the water weighed. The exhaust from the steam pump can be run into a barrel of cold water and the barrel weighed before and after.

The coal for the furnace should be weighed in barrows or barrels. It may be fired directly from the barrels or barrows or dumped on the floor before firing. The barrows should be weighed when full and empty and the time recorded in order that the weight of no portion be neglected. Any unburned coal must be weighed and the amount subtracted.

The condition of the fire should be the same at the beginning and at the end of the test. For a long test, 24 hours or more, the condition is estimated by the eye; if the test is short it is often started and stopped with bare grate bars.

Under a short test, the boiler must be in good working order about an hour before the beginning of the test so that the boiler, brickwork, etc., may be thoroughly heated. The fire is allowed to become low and by reducing the amount of steam taken from the boiler the pressure is kept up. About a half hour before beginning the test the fire is drawn and the grate cleaned. A new fire is quickly started with wood and when coal is first thrown on the test is started. Toward the end of the test the fire is allowed to burn low and at the end it is drawn out and quenched with as little water as possible. The unburned coal is picked out and its weight subtracted from the coal burned. The clinker and ashes are separated and weighed with the ashes and clinker formed during the test. The wood used is weighed and considered as equal to .4 the same weight of coal.

The temperature of the feed water can be taken best by means of a thermometer in a cup filled with oil and screwed into the feed pipe near the check valve. If the temperature is nearly constant, readings at intervals of fifteen minutes are sufficient; if it varies it should be read every five minutes.

The steam pressure shown by the gage ought to be as nearly constant as possible throughout the test and should be practically the same at both the beginning and end. Readings of the gage should be recorded every fifteen minutes and the fireman should read it more often to keep it constant. The gage should be tested and a correction allowed for if necessary.

Barometric readings also should be taken; two or three being sufficient for a 10-hour run. Barometer readings in inches of mercury are reduced to pounds pressure by multiplying by .491; .491 pound being about the weight of 1 cubic inch of mercury.

If a vertical boiler furnishing superheated steam is being tested both a pressure gage and a thermometer should be used so that the amount of superheating may be readily found by subtracting the temperature due to pressure (obtained from steam tables) from the thermometer readings.

The quality of the steam is determined from a throttling, separator or barrel calorimeter, the first or second being preferable on account of accuracy.

Samples of flue gas may be taken at intervals from various places; from the chimney, uptake and back of the bridge. The object is to determine whether there is sufficient air admitted or whether too much air of dilution is used. The determination of the constituents which form the flue gases is made by a chemical analysis.

The draft in the chimney may be measured by a U tube partially filled with water or by a draft gage.

The above are only a few precautions to be used during the test and merely serve as a guide. Many of these readings can be taken by any careful, intelligent person, but skill in conducting a test can be attained only by experience. As the chance for error is so great, care and accuracy must be used throughout, both during the test and while working up the data.

CARE OF BOILERS.

Starting the Fire. The fireman should first ascertain the water level; as the gage glass is not always reliable on account of impurities, foam, etc., the gage cocks should be tried. In a battery of boilers, the gage cocks of each should be opened, for the water may not stand at the same level in each. The safety valve should be raised slightly from its seat. If the fire has been banked over night, open the drafts and rattle down the ashes and clinkers from the grate. In case the fire has been allowed to go out, a new one may be started if the gage glass shows the proper amount of water and the valves work well.

If anthracite coal is used, first throw a thin layer of coal all over the grate, then place a piece of wood across the mouth of the furnace just inside the door and lay other pieces of wood at right angles to the cross piece with the ends resting on it. This allows a space under the wood for air. Now throw on coal until the wood is covered. The fire may be started with oily cotton waste, shavings, or any combustible material.

Keep the furnace door open and the draft plate closed until the wood is burning freely, which causes the flame to pass over and through the coal and to ignite it. The fire is then spread or pushed back evenly over the furnace bars; the furnace door closed, the ash pit door opened, as the draft requires, and more coal added when necessary. If bituminous coal is used, do not spread a thin layer over the grate bars under the wood.

The fire at the start should be slow, to cause gradual, uniform heating of the water and various parts of the boiler. If steam is raised too rapidly, enormous strains are set up, due to unequal expansion, thereby causing leakage at joints and perhaps rupture.

If the boiler is of the water tube type, steam may be raised more rapidly, because the amount of water is less and the joints are usually placed at some distance from the intense heat of the fire.

The fire being started, the method of adding coal depends upon the fireman, the kind of coal, the type of boiler, and the rate of combustion. There are three general methods of firing, — spreading, alternate or side firing, and coking.

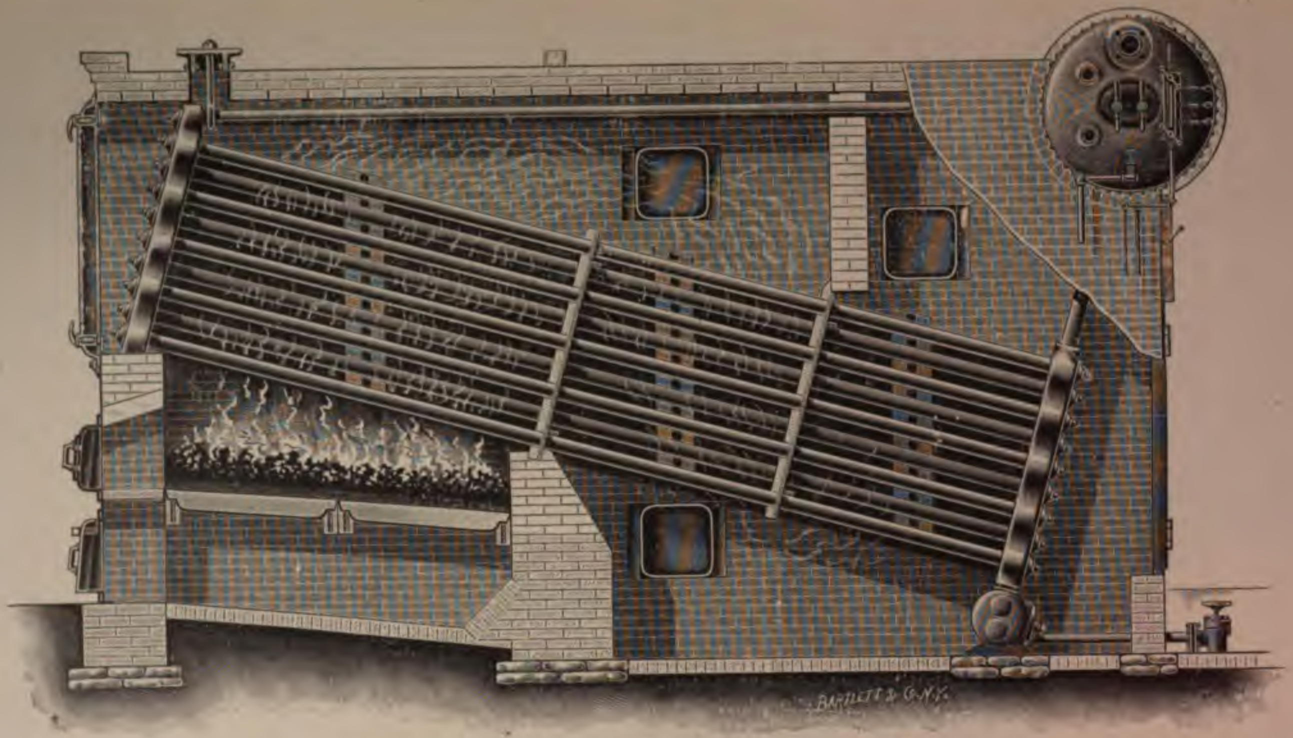
Spreading is accomplished by placing small amounts of coal uniformly over the entire surface of the grate at short intervals. By this method, the coal is thrown just where it is wanted and then not disturbed. The fire should be hollowed in the center, that is, it should be thicker at the sides. Good results are obtained from this method, since the fire can be kept in the right condition at all times, if the coal is of the right sort. During the operation of firing, the door should be kept open as little as possible or the fire will be cooled by the entrance of the cold air. For a short time, while the coal is giving off gas, the draft plate of the furnace door should be opened, in order that sufficient air may be admitted above the coal to burn the hydrocarbons.

When the alternate or side firing method is used, coal is spread so as to completely cover one side of the fire at one firing, leaving the other side bright. At the next firing, the bright side is covered. The hydrocarbons given off by the fresh coal are burned by the hot gases from the incandescent coal. This method is superior to spreading, because the entire furnace is not cooled off by the addition of fresh fuel.

Side firing is most advantageous with two furnaces leading to a common combustion chamber. The furnaces are fired at regular intervals with moderate charges of coal, and the draft plates are opened while the coal is giving off gas.

The two systems described above are best adapted to anthracite coal, since it burns with comparatively little smoke.

With bituminous coal, which is soft and burns with considerable smoke, the coking system is used. The coal is piled on the grate just inside the door, and allowed to coke from 15 to 30 minutes. During this time, the hydrocarbons are driven off and burned by the heat from the fire. In order to fully accomplish this, air must be admitted above the grate through the draft plates of the furnace door. The coke is then pushed backward over the fire and a new supply placed on the front of the grate. The air admitted prevents the forming of carbon monoxide gas and smoke. At the same time, it cools the furnace somewhat and reduces the rate of evaporation. This objection is not serious, unless a boiler must be worked to its fullest capacity in order to furnish the required amount of steam. If this is the case, economy is sacrificed to rapidity, for a low rate of combustion is usually more economical than a high rate. The necessary thickness of a bed for the best results is found by experiment. It depends on the draft and the kind of coal used. If the former is strong and the coal in large lumps, it may be thick, (about one foot) ; but if the draft is weak or if the coal is small, the bed must be thin (about three or four inches) so that sufficient air may pass through. In marine and locomotive work, with forced draft, the bed must be very thick to get a large coal consumption per square foot per hour.



Side View of Cross Drum Type of Babcock and Wilcox Boiler.

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With the same draft, bituminous coal may be fired more thickly than anthracite.

After finding from experiment the best thickness for the bed, keep it at that thickness. Always keep the bed of uniform thickness and never let the fire burn holes in the bed, and do not let the rear of the grate become bare. If a larger amount of steam is required, fire smaller quantities at more frequent intervals. Do not fire a large amount of coal and wait for the pressure to rise. The firing of fresh coal chills the furnace and temporarily retards combustion. It should be fired in small quantities and as quickly as possible. Keep the fire free from ashes and clinkers, but do not clean the fires oftener than is necessary.

Four tools are used for cleaning the fire. The slice-bar, the prick-bar, the clinker hook, sometimes called the devil's claw, and the hoe or rake.

The slice-bar is a long straight bar with the end flattened. It is used to break up clinkers by thrusting it between the grate and the fire. It is also used to break up caking coal. The prick-bar is similar to the slice-bar except that the end is bent at right angles like a hook. To remove ashes, the prick-bar is run along up between the grate bars from underneath. This bar is often made with detachable hook, so that the end may be replaced when burned off. The clinker hook, or devil's claw is used to haul the fire forward. The hoe, or rake, is used to draw out cinders, to haul the fire forward, etc.

In cleaning the fire, the fireman first looks to the water and steam. There should be enough water and sufficient steam pressure to last during cleaning. Then he breaks up the clinkers with the slice-bar and removes the ashes with the prick-bar. If it is necessary, he pushes the fire to the rear, thoroughly cleans the front of the grate bars, then hauls it forward and cleans the back of the furnace bars. Some firemen clean one side at a time instead of first the front and then the rear. The fire should be allowed to burn down before cleaning, but sufficient fuel, called chaff, should be left to start the fire quickly. Before cleaning, partly close the dampers so that the amount of cold air admitted will be small. For this reason and to prevent loss of pressure, clean as rapidly as possible.

Banking the fire depends upon the condition of the fire, the fireman himself and the length of time it is to remain banked. First clean and place all the coal in a small space at the bridge, then cover with fresh coal to a depth depending on the length of time the fire is to remain banked. Then close all dampers and open the door. Some firemen cover the front of the furnace bars with ashes.

To start from a banked fire, first examine the condition of the water level, steam pressure, safety valves, etc. Then clean the fire with the slice-bar and rattle down the ashes with the prick-bar. After spreading the coal evenly over the grate cover with a thin layer of coal and open the dampers.

Condition of Water. The first duty of the engineer or fireman is to know at all times the height of water in each and every boiler under his care. The gage cocks should be tried frequently, because the water gage is not always reliable. The fires should never be unbanked nor replenished without sufficient water in the boiler.

Gage Cocks and Water Glasses should be kept clean and in constant use. This is important because if the connections become clogged by dirt and impurities, the gage glass will not show the true level.

The Safety Valve. These valves should be of ample size and in good working order. They should be raised cautiously and frequently, as they are likely to stick to their seats if seldom used, or if the feed water is corrosive. They should be tried at least once a day.

The Pressure Gage. The pointer of the pressure gage should stand at zero when there is no steam pressure in the boiler. If it does not, it should be corrected and compared with a standard gage. If the gage indicates the limit of pressure and the safety valve does not blow off, bank the fire; also if convenient, test the gage and if found to be correct, investigate the condition of the safety valve.

Fusible Plugs. Whenever the boiler is cleaned these safety devices should be cleaned on both sides. They should be scraped if necessary. If not kept clean they are likely not to act.

The Ash Pit. Keep the ash pit clean to prevent the excessive heat underneath from burning the grate bars. If the ash pit is shallow, it is often filled with water to a depth of about two inches.

Cleaning. All parts of the boiler which are exposed to the fire should be kept clean. All tubes and flues should be swept as often as possible. The frequency of cleaning depends upon the kind of fuel and the nature of the water. No boiler is economical if the heating surfaces are allowed to become covered with a thick bed of soot and dirt. The layer of dirt should never be over $\frac{1}{16}$ of an inch in thickness. Handholes and manholes should be frequently removed and surfaces examined and cleaned. In replacing handhole caps and manhole covers, clean the machined surfaces without scratching, smear with oil and screw up tight. The boiler should be emptied as often as once in two weeks and even more often if the feed water is impure. The surface blow-out should be opened when there is no demand for steam. If the water is muddy, or comes from a condenser and contains oil, five or six inches of water should be blown out every day. Never blow off when the steam pressure is high. Make sure no water is escaping when the blow-off cock is supposed to be closed. Scale should be prevented if possible, but if it is formed, it should be removed frequently as it is a poor conductor of heat, thereby reducing the efficiency of the heating surfaces and rendering them likely to burn. Scale may be removed by any one of several methods, but those which require sharp tools, or which cause unequal expansion should never be used, as the boiler may be seriously damaged.

Feed Apparatus. It is good practice to have two independent ways of feeding the boiler. The pump and the injector should both be of sufficient capacity to supply the feed water and whichever is in use should be run as uniformly and continuously as possible. Check valves and feed valves should be examined and cleaned frequently. Cold water should never be fed into any boiler when it can be avoided. But if it is necessary to do so, it should enter the boiler so that it will not come in contact with the plates before it has mixed with the warm water in the boiler.

Low Water. In case of low water, cover the fire with wet ashes, or fresh coal if ashes are not convenient. Draw the fire as soon as may be without increasing the heat. Do not admit more cool water. Do not start or stop the engine or lift the safety valve. Never fill a hot boiler with cold water as leaks and fractures may result.

Foaming. Close the throttle or stop valves and keep it closed until the water becomes quiet and shows the true level. Foaming, if caused by dirty water, can usually be stopped by blowing off and feeding fresh water. If the boiler primes, lower the water line.

Blowing Off. Never empty a boiler while it is hot, because the deposits of sediment and grease will become baked on the heating surfaces and will have to be removed by mechanical means. One of the best methods of preventing scale is to allow the boiler to cool gradually and stand a few days with cold water in it before emptying.

Dampness. The exterior of boilers should be examined frequently, especially if the location is damp, or there is much brickwork setting. No water should come in contact with the exterior of the boiler, either from leaky joints or other sources, as it causes corrosion. Do not allow the covering to become damp.

Air Leaks. The admission of air from the brickwork to the combustion chamber, or to the flues is a source of loss.

The boiler should often be examined for blisters, cracks, and defective joints, and if any appear, should receive prompt attention.

Galvanic Action. If galvanic action between the water and the copper and iron is suspected, hang a piece of zinc in the boiler.

If a boiler is to stand unused for some time, it may be kept in good condition by any one of several methods. It may be completely filled with water in which a quantity of common soda has been dissolved, or it may be emptied, thoroughly dried, and trays of quicklime placed in the bottom. The boiler is then sealed as nearly air tight as possible.

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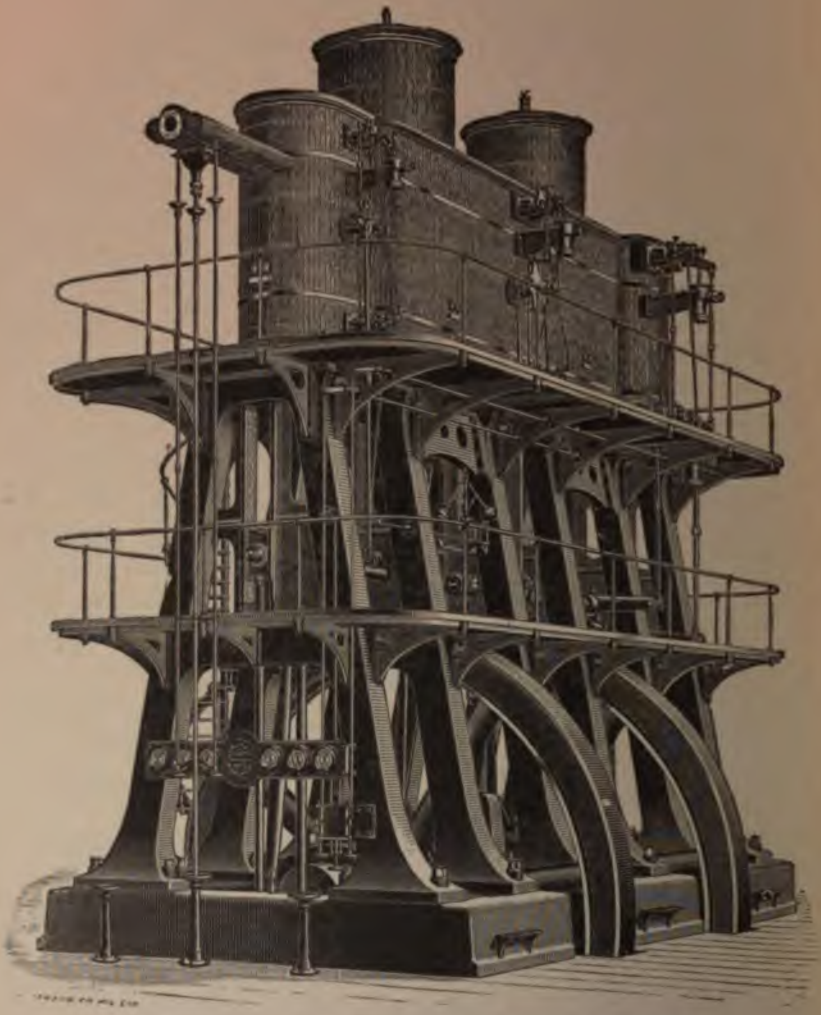

VERTICAL TRIPLE EXPANSION PUMPING ENGINE
ALLIS-CHALMERS COMPANY

STEAM PUMPS.

Principles of Action. A pump is primarily a machine designed for lifting liquids, or for conveying them to a distance through pipes, or both. To accomplish these results may be used the principles of suction, lifting, or forcing or any combination of them; in practice generally the first is combined with one of the other two.

Suction, so-called, is really the pressure due to the weight of the atmosphere acting to force the liquid into a space wherein a partial vacuum has been created by removing a part of the matter that filled it. The amount of pressure available in any instance for forcing in the liquid, depends upon the completeness with which the matter has been removed from the space in which suction is acting, and on the weight of the atmosphere at that place. If all matter could be removed from the suction chamber, a perfect vacuum would be created and the full pressure of the atmosphere would be effective; a condition closely approaching this is created in the barrel of a pump when no air is present and the plunger or part of the liquid is withdrawn.

If there be any air present, it will expand and fill the vacant space, its pressure falling as the volume increases; the pressure available to force in the liquid by suction will be the difference between that due to the weight of the atmosphere and the final pressure in the suction chamber. The greater the amount of matter removed from the suction chamber, the less will be the resulting pressure therein and the greater the difference available for moving the liquid.

The other factor, the weight of the atmosphere, varies with its condition and the altitude as shown by the barometer. The following table compiled from "Kent's Mechanical Engineers' Pocket Book" and "Nystrom's Mechanics" gives barometer readings, the pressure per square inch, and heights above sea level corresponding to each other; the altitude being at 40° latitude and temperature 60° Fahrenheit.

TABLE I.

Barometric Reading in Inches of Mercury.	Atmospheric Pressure in Pounds per Square Inch.	Altitude above Sea Level in Feet.
30	14.72	0
29.75	14.60	232
29.50	14.47	466
29.25	14.35	703
29.00	14.23	941
28.75	14.11	1181
28.50	13.98	1424
28.25	13.86	1668
28.00	13.74	1915
27.50	13.50	2415
27.00	13.26	2924
26.50	13.02	3443
26.00	12.77	3972
25.50	12.53	4511
25.00	12.27	5061
24.50	12.03	5621
24.00	11.78	6194
23.50	11.54	6778
23.00	11.30	7375
22.50	11.05	7985
22.00	10.80	8609
21.50	10.56	9247
21.00	10.31	9900
20.00	9.81	11254
19.00	9.32	12678
18.00	8.82	14179
17.00	8.33	15766
16.00	7.84	17448
15.00	7.35	19240
14.00	6.86	21155
13.00	6.37	23212
12.00	5.88	25433
11.00	5.39	27848

As the weight of a column of water one foot high and one inch square is 0.433 pound, it follows that the atmospheric pressure, which at sea level is ordinarily 14.72 pounds per square inch, can support a column of water as many feet high as 0.433 is contained in 14.72 or 34.2 feet. The height of column which can be supported decreases as the altitude increases. At the top of a mountain two miles high it would be only 9.81 ÷ 0.433 = 22.7 feet.

This is the height which could be barely supported if the vacuum were perfect. In practice the height to which water can be lifted is much less, because it is impossible to obtain a perfect vacuum on account of leakage of valves and joints, and the atmospheric pressure must overcome friction in pipes and passages, so that the possible lift is reduced to not over 25 feet at sea level and this only for slow working. It is better to attempt only 20 feet or even less if the pump is to work rapidly. If, however, a high suction lift is imperative, it may be obtained by admitting air with the water in suitable proportions to form a heavy spray so that the weight per cubic foot of the mixture is considerably reduced. In this way a lift of as much as 100 feet may be possible but of course, at the expense of the weight of water pumped per stroke, so that either the pump must be run at a higher speed or a larger pump must be used. The air should be admitted to the suction pipe through several small openings a little above the level of the water in the supply reservoir. The suction must be primed each time the pump is started.

Probably the earliest example of a practical steam pump was that built at Raglan Castle by the Marquis of Worcester in 1630. This employed both suction and pressure, two vessels making the flow continuous. Steam was admitted from a boiler through valve B′, Fig. 1, to the chamber A′, and the pressure forced the water upwards through the valve F′ and pipe E; the valve C′ preventing its return to the reservoir. Meantime the chamber A was shut off from the boiler, and the cold water, condensing the steam, caused a partial vacuum so that water was forced up through valve C and pipe D into the chamber A. When A′ was emptied and A filled, the steam valves were reversed and A′ became filled while A was being emptied.

Practically all pumps, except those to which the liquid comes under pressure, use the suction principle for filling their cylinders. The suction lift is, however, usually but a few feet except where deep mines are drained, and in the case of air pumps for condensers in which the suction is always kept at the highest possible value. In order to improve the suction action, valves and supply pipes must be kept with all seatings and joints absolutely tight.

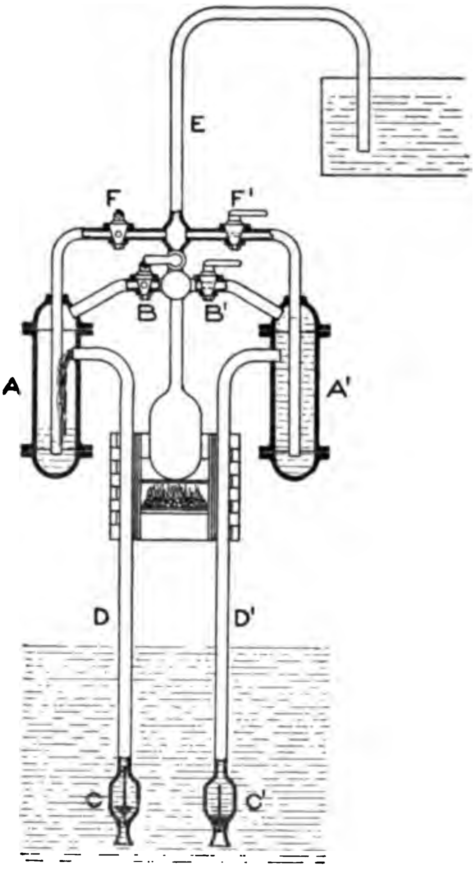

Fig. 1.

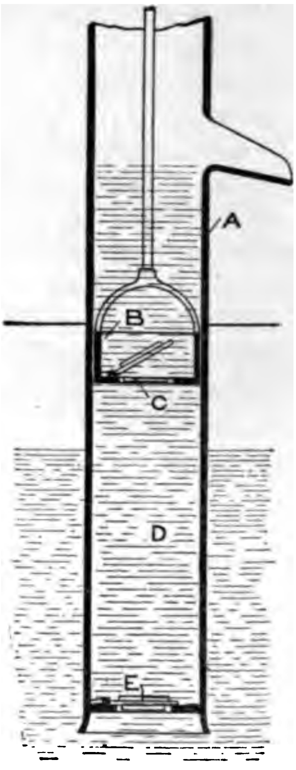

Fig. 2.

Lifting. The lifting pump is simply a bucket B, Fig. 2, working in a vertical barrel A and so arranged that the water is caught above the bucket and raised on the upward stroke to the top of the barrel or to a point where an overflow is provided. Usually the bucket is filled on the down stroke by means of a valve

C in the bottom, and if the lift is for any considerable distance, it is necessary to put a foot valve E at the bottom of the inlet pipe to prevent the liquid from sinking in the barrel when the bucket descends. By this means suction also is introduced, since the space D above the foot valve is filled from the reservoir by suction during the up stroke of the bucket. The pump may then be placed at any distance above the reservoir within the limit already stated, and at any distance horizontally; but it should be remembered that the speed of working and height of lift must be decreased if the horizontal distance is materially increased, and that it is always better to make the suction pipe as short as possible.

Forcing. The suction effect is used in all pumps, at least to fill the barrel, but the lifting principle is uncommon except where the discharge is to be directed from a spout at the top or in the side of the barrel, as in mine drainage and house pumps. If it is necessary to raise the liquid to a point above the pump level, either a piston or a plunger working in a closed chamber is used to force the liquid through discharge valves, against whatever pressure may be necessary, into the delivery pipe; return currents being prevented by the closing of the discharge valves.

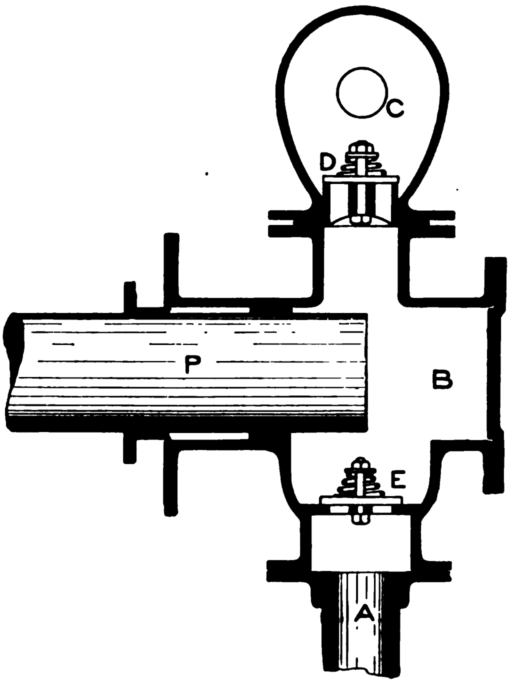

Fig. 3.

As seen in Fig. 3, the plunger P on the outward stroke draws water from the reservoir through pipe A and inlet valves E into the barrel B. On the inward stroke, the valve E will close and, since liquids are practically incompressible, the discharge valves D will open allowing the water to pass into the discharge chamber and out the pipe C. Fig. 3 represents a single-acting plunger pump, but the action is the same for a piston or for a double-acting pump except that there are two sets of valves. Although the force is exerted on the mass of liquid in a direction lengthwise of the barrel, yet, since pressure is transmitted equally in all directions, the valves will open promptly if located in any position with respect to the barrel.

The pressure against which the pump must act in forcing depends on the weight of the valves, the spring pressure, if any, used to close them quickly and the height to which the liquid is to be raised, or as it is technically termed, the "head," against which the pump is to work. For water, the pressure per square inch increases one pound for every 2.32 feet, or as previously stated one foot of head produces 0.433 pound pressure per square inch. There is no theoretical limit to the height to which a liquid may be raised by forcing, but the speed of starting and stopping the column of water, that is, the number of strokes per minute, must be decreased as the delivery pipe becomes longer, if water-hammer is to be avoided; this is true whether the length be horizontal or vertical. This hammer effect is due to the force necessary to overcome the inertia of the column of liquid and start or stop its motion. If not properly taken into account, either by using slow speeds or providing adequate air chambers to take up the shock, it will always produce destructive results. Wear on the outlet valves also limits the height to which water may be forced, as this wear increases with the head and makes it difficult to keep the valves tight.

Usually no special precautions are required up to pressures of 500 pounds per square inch; above this, care must be exercised up to the limit of 2,000 pounds, which is as high as will be required for lifts or presses except in special cases. Anything above this requires the greatest precautions, not only as to strength of parts, form of valves and packing of joints, but even with respect to quality of castings. Water will sometimes leak through what appears to be solid metal.

The pressure produced by water-hammer is taken advantage of in one special form of pump, **the hydraulic ram,** in which the

TABLE II.

Head in feet.	Pressure pounds per square inch.	Head in feet.	Pressure pounds per square inch.	Head in feet.	Pressure pounds per square inch.
1	.43	46	19.92	91	39.42
2	.86	47	20.35	92	39.85
3	1.30	48	20.79	93	40.28
4	1.73	49	21.22	94	40.72
5	2.16	50	21.65	95	41.15
6	2.59	51	22.09	96	41.58
7	3.03	52	22.52	97	42.01
8	3.46	53	22.95	98	42.45
9	3.89	54	23.39	99	42.88
10	4.33	55	23.82	100	43.31
11	4.76	56	24.26	101	43.75
12	5.20	57	24.69	102	44.18
13	5.63	58	25.12	103	44.61
14	6.06	59	25.55	104	45.05
15	6.49	60	25.99	105	45.48
16	6.92	61	26.42	106	45.91
17	7.36	62	26.85	107	46.34
18	7.79	63	27.29	108	46.78
19	8.22	64	27.72	109	47.21
20	8.66	65	28.15	110	47.64
21	9.09	66	28.58	111	48.08
22	9.53	67	29.02	112	48.51
23	9.96	68	29.45	113	48.94
24	10.39	69	29.88	114	49.38
25	10.82	70	30.32	115	49.81
26	11.26	71	30.75	116	50.24
27	11.69	72	31.18	117	50.68
28	12.12	73	31.62	118	51.11
29	12.55	74	32.05	119	51.54
30	12.99	75	32.48	120	51.98
31	13.42	76	32.92	121	52.41
32	13.86	77	33.35	122	52.84
33	14.29	78	33.78	123	53.28
34	14.72	79	34.21	124	53.71
35	15.16	80	34.65	125	54.15
36	15.59	81	35.08	126	54.58
37	16.02	82	35.52	127	55.01
38	16.45	83	35.95	128	55.44
39	16.89	84	36.39	129	55.88
40	17.32	85	36.82	130	56.31
41	17.75	86	37.25	131	56.74
42	18.19	87	37.68	132	57.18
43	18.62	88	38.12	133	57.61
44	19.05	89	38.55	134	58.04
45	19.49	90	38.98	135	58.48

force produced by the inertia of a large column of water suddenly checked is utilized to raise a small column against a high pressure. The working of the apparatus is seen from Fig. 4. Water flowing from pipe F into the chamber A will escape through valve V (closed in the figure) to discharge pipe D; but, as the velocity of flow increases, valve V will be lifted and closed checking the flow of water. The force thus developed will open valve V′ against the pressure of the spring and the head of water in the small pipe E, and some water will be forced into chamber B and up pipe E or into the air chamber C compressing the air. Water will pass into B until the force due to water hammer is so decreased that valve V′ closes and valve V opens once more, when water will again overflow and the process be repeated. The head against which the ram will work may be almost any amount, but the ratio of water raised to that wasted at the overflow will decrease as the head on valve V′ increases. In any case, the ratio will be small and the ram wasteful, so that its use is advisable only where the supply of water is almost unlimited, other power is difficult to procure, or the amount to be raised is very small. Table III gives the relation of efficiencies and ratio of lifting to forcing heads, which according to D. K. Clark, may fairly be expected with a ram of good design.

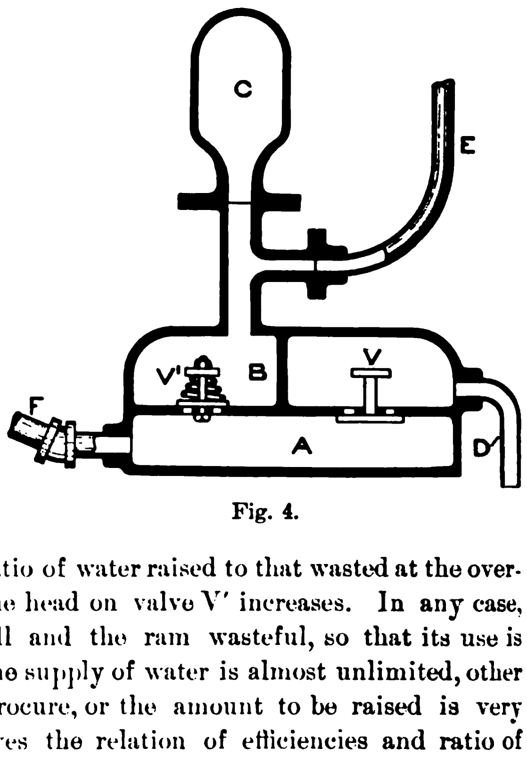

Fig. 4.

TABLE III.

Ratio of lift to fall	4	6	8	10	12	14	16	18	20	22
Efficiency per cent	72	61	52	44	37	31	25	19	14	9

The ram should be arranged with a drive pipe whose length is at least five times the fall, in order to give a long column of moving water and increase the water-hammer. The diameter of drive pipe is usually twice that of the lift pipe.

KINDS OF PUMPS.

In classifying pumps, the division may be made according to any one of several methods: As to the principles of action, the details of construction, the means of driving, or the purposes for which they are used. With respect to principle of action the classes may be:

1. Lifting,
2. Forcing,
3. Combinations.

With regard to the details of construction:

1. Jet,
2. Rotary,
3. Centrifugal,
4. Reciprocating.

With regard to uses, the division is difficult, since the same pump is frequently used in different places for different purposes. Such classes as tank pumps, boiler-feed pumps, air pumps and mine pumps are fairly definite, but the details vary so much with different makers that it is impossible to draw sharp distinctions.

From the discussion of the principles of action we know that practically all power pumps are of the third class, that is, work by a combined lifting action due to suction and forcing. But the second classification is yet to be considered.

The Jet Pump. The first variety, the jet pump, is perhaps best known in the form of the injector, but the principle is worthy of a much wider application than it now has. In the form of a steam or water ejector it may be used for lifting water by suction and raising it to a considerable height, while its simplicity and ease of application give it a large field of usefulness. A convenient form for an ejector is shown in Fig. 5. The propelling jet may be either steam or water under pressure entering through the valve A and flowing from nozzle D which should be made with a decreasing taper like a hose nozzle. If steam is used, it will be necessary to provide a small injection pipe with valve for supplying water to condense the jet and create a vacuum at the start, otherwise the steam will blow through the apparatus and will not lift the water in the suction pipe. In this case, the heat energy of the steam will be converted into velocity, and will be available for drawing and forcing the water so that it can be raised to a considerable height. The efficiency of a well-designed steam ejector should be nearly equal to that of an injector and will, like that, depend on the temperature of the water and the height of the suction and lift.

In pumping into a boiler, the efficiency of an injector is nearly 100 per cent because nearly all the heat energy which is lost in friction goes to heat up the feed water and is therefore utilized;

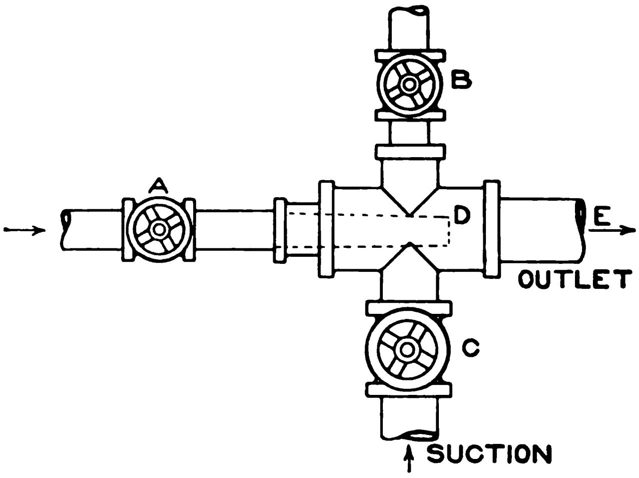

Fig. 5.

but for other purposes, the injector or ejector is wasteful of heat and cannot be considered economical. Its convenience, however, is a strong point in its favor, and where the amount of water to be lifted is not large, or if it is to be used only occasionally, it will often pay to use it rather than to install a more elaborate and costly pump.

When water under pressure is used as driving power, it is not necessary to have the inlet at B. The flow of the water from the nozzle will carry along the air and create a vacuum at D which will draw the water up the pipe C. There is no heat energy available as in the case of steam, so that the water can furnish only such an amount of power as is due to its weight and the velocity with

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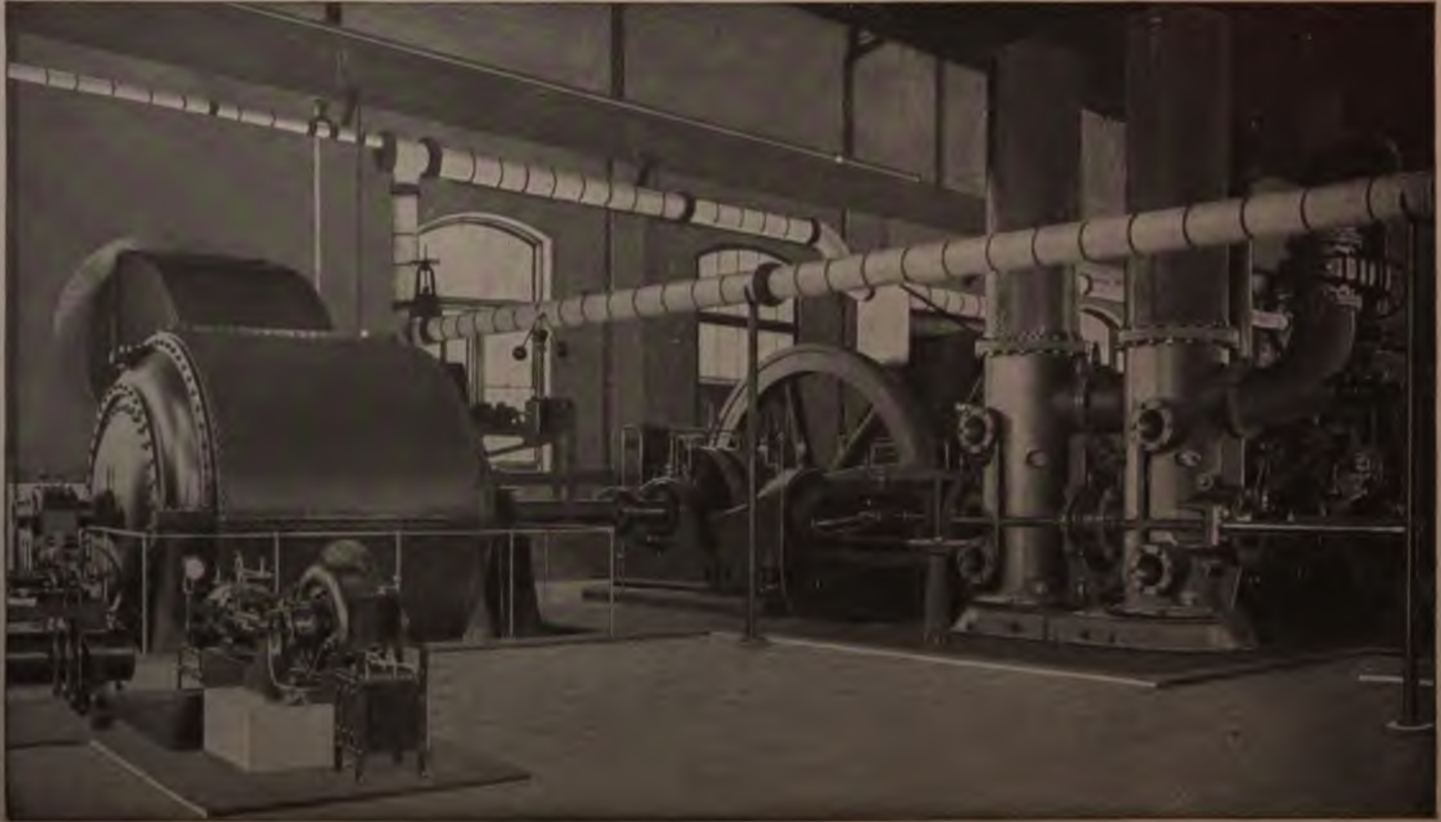

PUMPING STATION WITH RIEDLER DUPLEX PUMP,
Driven by Corliss Engine or by Direct Connected Water Turbine.

which it leaves the ejector nozzle; and, as the efficiency is low, not over one fourth of the energy furnished to the ejector at A will be available to move water at E. For a water injector it is well to proportion the pipes so that the head on A times the area of D equals twice the suction and lifting heads combined multiplied by the area of C; and to make the area of E equal to the area of D plus the area of C, if the apparatus is to be used as a water ejector. For steam, a ½-inch pipe at A for a 2-inch at C and a 2½-inch at E has been found to work well when the head on E was small, and if the water is under city pressure a ⅜-inch pipe at B.

It is well to remember that the energy of a jet of either steam or water depends more on the velocity than on the weight flowing, since the energy available per second equals $\frac{W v^2}{2g}$ where W is the weight flowing per second, v is the velocity in feet per second and g is the acceleration due to gravity; therefore, for good efficiency, it is best to use high pressure whenever possible.

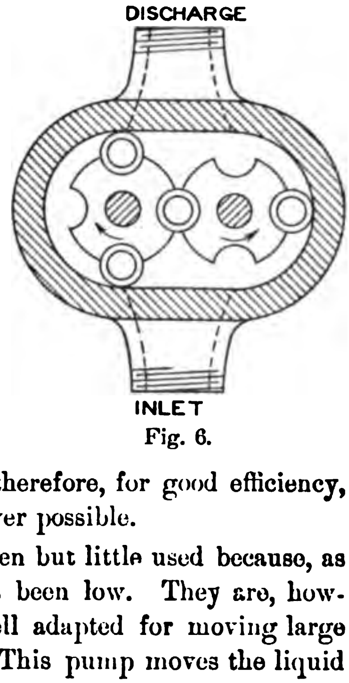

Fig. 6.

Rotary Pumps. These have been but little used because, as usually designed, their efficiency has been low. They are, however, useful in many cases and are well adapted for moving large volumes of liquid at low pressures. This pump moves the liquid by catching it between the lobes of the revolving propellers and the casing of the pump and sweeping it around from the suction pipe to the discharge; its return being prevented by the obstacle of the lobes and cylinders in the center. All are made on the same principle, the difference being in the design of the lobes and cylinders.

These are of many forms, but two will be sufficient to illustrate the principles. Fig. 6 is the Berrenberg; here the lobes are made by two pieces of tube fastened opposite each other. The tubes extend from the semi-cylindrical openings and make a joint with the other lobe by fitting in as shown. The axles are geared together outside the casing and are supported by bearings inside and outside, which are tapered to allow taking up wear and keeping the shafts true. The curves in Fig. 7 show the results from a series of tests made on a 2-inch pump by Mr. R. A. Hale and recorded in Barr's "Pumping Machinery." These show that the efficiency of the pump increases with the pressure against which it is working up to a certain point, and then falls off, while comparison of the curves at different speeds shows that the efficiency becomes less as the speed increases. This is apparent because the loss from friction is not doubled by doubling the head, while the amount of water will be the same per revolution, no matter what the pressure may be. The exception to this is due to slip which increases as the pressure becomes greater. Hence the useful work will increase up to that point where the loss due to leakage and friction more than balances the increase of work due to the increased head. The same reasoning applies to the speed, except that in this case the friction work will increase in proportion to the speed, so that the gain from the added work due to the increase of speed is not as great as from increase of head.

RELATION OF EFFICIENCY TO PRESSURE
FOR ROTARY PUMPS.

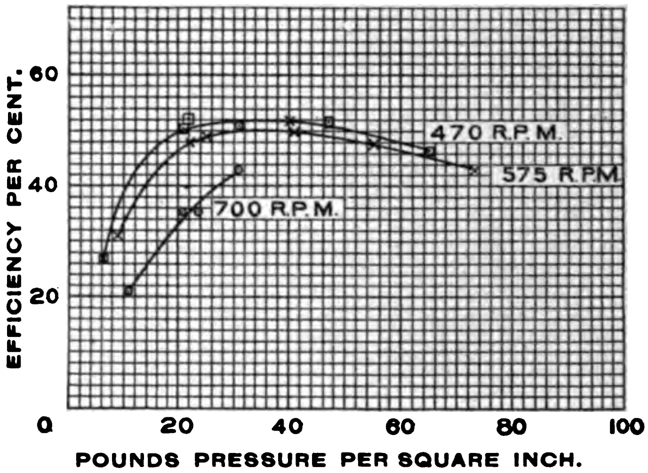

Fig. 7.

Another style of rotary pump is shown in Fig. 8 in which the two pistons are so designed that their bounding surfaces are always in contact, thus forming the joint. In this type it is important that the surfaces be of the correct shape, otherwise a pocket will be formed in which water will be caught. This water will be compressed as the volume of the pocket becomes smaller. As water is practically incompressible, it must either leak past the joint or burst the pump. In order to prevent this, a port is sometimes cut in the casing to allow the water to bypass and relieve the pressure. If, however, the outline of the lobes is made of the right shape, there will be no compression and the ports will not be necessary. It has been demonstrated that the curves to use for the outline of the lobes are the cycloids, as they can form the whole outline and will make a smooth surface which will not create pockets at any part of the revolution. The involute curve has sometimes been used, but it is not good as it does not return on itself, and must therefore be cut off by the arc of a circle on the end of the lobe, leaving corners which form compression pockets.

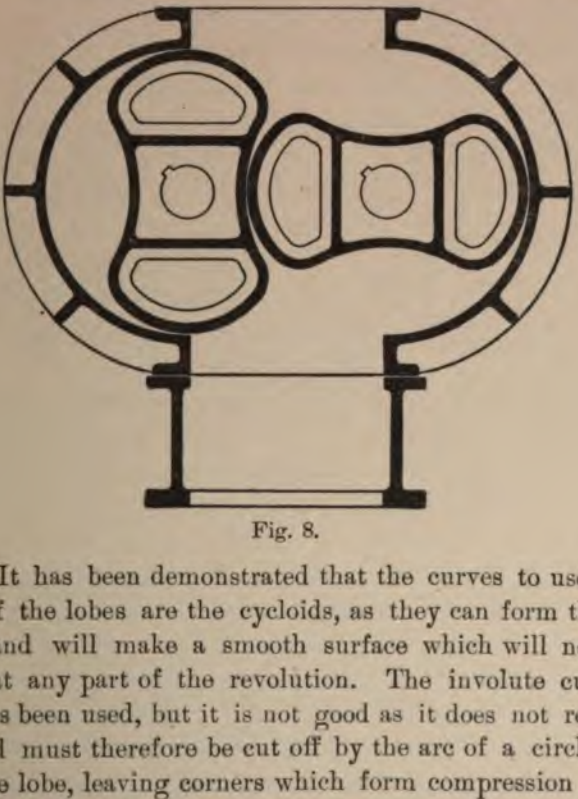

Fig. 8.

With respect to the effect of the speed on the volume of water pumped, the experiments above noted showed that, within the stated limits, the volume varies nearly as the speed, and that at the same speed, the volume is a little less at high pressure than at low, but does not fall off rapidly as the pressure increases. The data, however, is not complete enough to be conclusive.

The rotary pump is often used for fire purposes, and where portability is of more importance than efficiency, or if first cost is a great consideration. It can be run at high speed, and has a large capacity for the space occupied, but it is not suitable for large or permanent work except at very low heads.

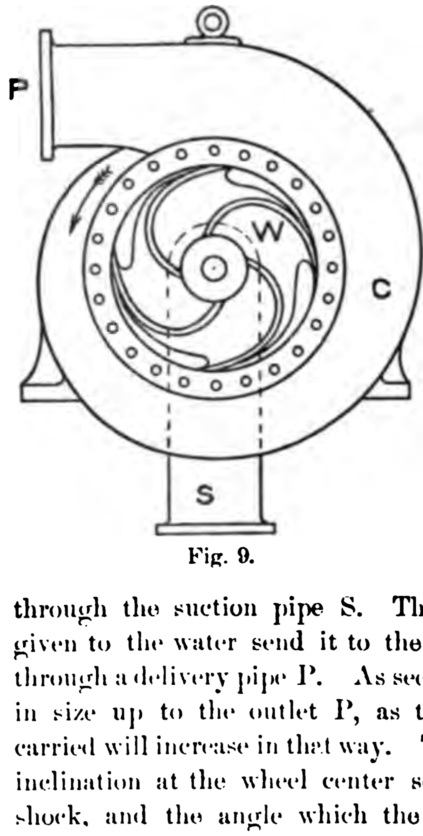

Fig. 9.

Centrifugal Pumps. These operate by the familiar force which throws the mud from the carriage wheel and the water from the lawn sprinkler. A wheel W (Fig. 9) with curved blades revolves in a casing C and, when the casing is filled with water, throws it to the outside thus creating a suction at the center and drawing up water through the suction pipe S. The velocity and whirling motion given to the water send it to the outside of the casing and out through a delivery pipe P. As seen in Fig. 9, the casing increases in size up to the outlet P, as the volume of the water to be carried will increase in that way. The blades are given a backward inclination at the wheel center so that water may enter without shock, and the angle which the blades make with the radius is increased towards the outer end so that the water gradually attains some rotary velocity and great radial velocity due to the wedging action as it passes outwards; on leaving the blades it has high speed. If the blades are radial at the outer end, the discharge will be greater for a given speed, but it will not be possible to reduce the speed much without stopping the action altogether; also the efficiency will be less.

Rankine states that the curve of the blade should be an involute of a circle, that is, a curve drawn by a point in a string as it is unrolled from the circle as shown in Fig. 10. The method of drawing the involute is as follows: Let BC be the inner bounding circle of the blades and B the point at which a vane is to start. Draw a radius of the circle through B and through the same point at an angle of 40 degrees with the tangent, another straight line BE. Draw a concentric circle tangent to BF, which is perpendicular to BE. If B were a point in a string, and this were unrolled from the circle, the point B would trace an involute BGH. For the first form of curve mentioned, this would be continued to the outer bounding circle where it should make an angle of about 15 degrees with the tangent, as LHM. For the Rankine blade, the reverse curve HKA should be drawn, usually the arc of a circle radial at the point H. In order to work without shock, the angle of the blade with the tangent at the inside end B should be such that its tangent equals the radial velocity of the water divided by the circumferential velocity of that point on the wheel; it is often made 40 degrees, which is found to be satisfactory for the average case. The angle at the outside should be 15 degrees if there is no diffusing chamber, or if the discharge pipe is not of increasing diameter, in order to gradually lessen the velocity of the water after it leaves the wheel. But this will necessitate a high rotary velocity of the blades, and it is sometimes better to use a diffusing chamber (or an increasing discharge pipe), and make the blades of the Rankine form, running the wheel at a lower speed unless the conditions make it necessary to be able to run at a given medium speed for a partial discharge. The casing should be shaped to give the water a gradually increasing velocity from the time that it enters the suction pipe until it reaches the circumference of the fan, and then a decreasing velocity until it leaves the discharge pipe. The spiral casing is often recommended because the centrifugal force given by the rotary motion is radial, not tangential, and the water must be

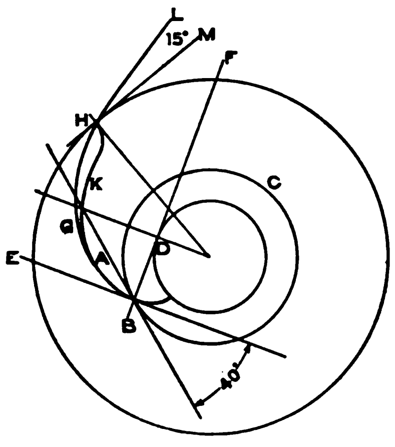

Fig. 10.

given time to change its direction or it will spend much of its energy in eddies and useless work.

Three styles of blades are shown in Figs. 11, 12 and 13. Fig. 11 is the form used for small sizes and for thick liquids; Fig. 12 is a hollow-arm type used in large pumps; it has the advantage that the water is thrown outward without any churning motion, and that there are no dead spaces. Fig. 13 is the style used for dredges and has the advantage that the sand is kept from grinding between the blades and the casing yet large openings are free for the passage of sand and mud.

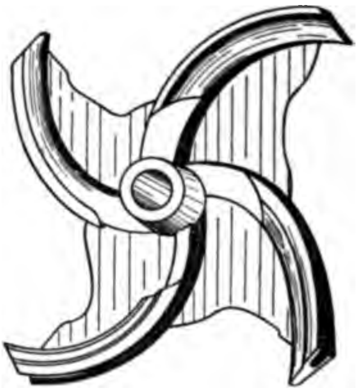
Fig. 11.

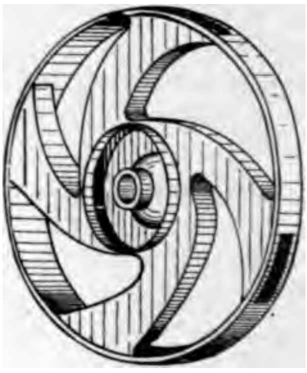
Fig. 12.

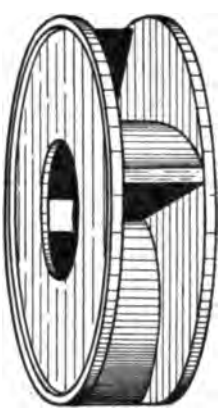
Fig. 13.

It is possible to raise water to any height up to 100 feet by increasing the speed of the pump, but it has been shown by experiment that this form is not suitable for lifts of over 25 feet, although up to 35 feet the efficiency is fairly good. As it is at these low lifts that the reciprocating pump is least efficient, this is clearly the field of the centrifugal pump.

The speed is increased as the height of the lift increases, but not in exact proportion, because the increase of speed for an increase of 10 feet in lift is greater at low than at high heads. Fig. 14 shows the relation between head and speed in two pumps of the same make, the No. 2 having a capacity of 100 gallons per minute at the speeds given and the No. 6 a capacity of 1,200 gallons. The point at which the curves cut the axis of speed shows that the No. 2 pump will fail to work at a speed below 250 r. p. m. and the No. 6 below 125 r. p. m. The pump may be set in either a vertical or a horizontal position and may have the suction on one side or both. However, it is better on both so that the forces due to lifting the water in the suction pipe are balanced and no end thrust produced. It is necessary to have some means of filling the pump casing with water, that is, "priming" it, as the suction will not start until the pump is so primed. If water under pressure is not available, it is necessary to install a steam injector to fill the casing, or provide a foot valve which will be tight enough to hold the water in the suction pipe at all times.

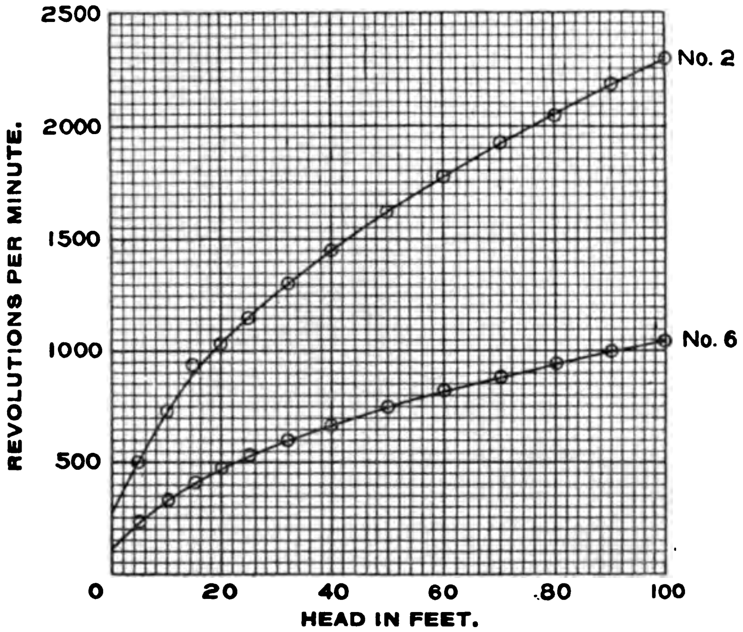

Fig. 14.

Makers recommend that a flap valve be installed at the top end of the discharge pipe also, to assist this action. Fig. 15 shows an arrangement which is satisfactory and also gives an idea of the shape and relative proportions of a standard centrifugal pump.

Lifting Pumps. The only pumps which work entirely by lifting are the old-fashioned chain devices in which a series of discs mounted on a chain are drawn, by a sprocket wheel, up through a tube bringing the water with them. In this form the motion is always in one direction, and there is a purely lifting action. But it is common to speak of the pump which delivers its stream by lifting, as a lifting pump even though it is filled by the action of suction. These are used largely in mines and for domestic purposes. The principle has been shown in Fig. 2. The disadvantage of this style is that the pump bucket must be not over 20 feet above the water and the rest of the lift must be made by the rise of the bucket, necessitating either a long rod, or pumping in relay. The greatest use of this class was in the Cornish mines in the time of Watt when the engines were placed at ground level, and the rods made of a length sufficient to reach to within 20 feet of the bottom of the shaft. In some cases these pump rods were as much as 480 feet long, and the design of the great pieces was a difficult problem. The walking-beam engine was used largely to drive the pumps, and the whole machine was a huge and wasteful affair. At the present time, the long pump rod is used to some extent, but it is driven by a vertical cylinder set over the top of the mine shaft.

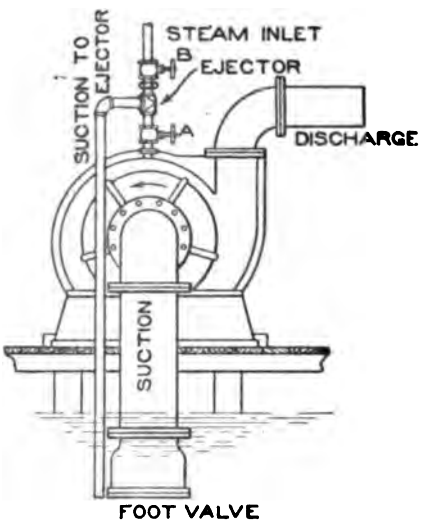

Fig. 15.

The size of the pump cylinder depends upon the volume of water to be raised and the speed of the pump. When heavy masses are to be moved, as is the case when long rods are used, the speed must, of course, be slow. For the great engines of Watt's time it was about 15 strokes per minute, and in modern pumps it is 25 to 35 strokes per minute. The cylinder must be made of such size that at this speed it will lift the required amount of water.

For example, if it is desired to raise 100 gallons per minute, and the pump is to run at 30 strokes, the volume to be raised is $100 \times 231 = 23{,}100$ cubic inches, and the volume per stroke is $23{,}100 \div 30 = 770$ cubic inches. A usual value for the stroke of pumps of this size is 16 inches which (if there were no allowance for leakage) would make the area of the cylinder $770 \div 16 = 48.13$ square inches. The allowance for leakage or slip should be, for a pump of this size and speed, about 3 per cent. This would, of course, increase with high speed and decrease with large size. Allowing 3 per cent slip, the area should be $48.13 \times 1.03 = 49.58$ square inches which is that for a circle of about $7\frac{15}{16}$ inches diameter, so that 8 inches would be used and the area would then be 50.26 square inches.

To find the force needed to lift this bucket, it is necessary to know the height to which the water is to be raised. Suppose this to be 200 feet; then the pressure per square inch will be $200 \times .433 = 86.60$ pounds and the force needed, $86.60 \times 50.26 = 4{,}352+$ pounds To this must be added the weight of the bucket and rod as both must be lifted at each stroke by the driving head at the top of the shaft. The rods are usually made of wood with the sections fastened together by iron couplings. The proper size for the above pump is 4 inches diameter, which for a rod 200 feet long would weigh, at 45 pounds per cubic foot, $45 \times \frac{\pi \times 4^2}{4 \times 144} \times 200 = 785$ pounds (about), and the bucket and fastenings will easily make this 1,000 pounds; the whole weight to be lifted will then be 5,352 pounds, which, at 30 strokes per minute, will call for the expenditure of

$$\frac{5{,}352 \times 30}{33{,}000} \times \frac{16}{12} = 6.5 \text{ H. P. (nearly)}$$

This would be the power necessary to run the pump aside from the friction of the machinery.

Although, at the present time, high lifts are largely made by using a forcing pump at the bottom of the shaft, this was not known at the time of the introduction of the pumping engine in the Cornish mines, and when it was necessary to raise water from a depth greater than could well be handled in one lift, it was accomplished by using pumps in relays. One engine would be installed at a depth of some 240 feet from the bottom of the mine, with its pump cylinder within 20 feet of the bottom, and would raise the water into a reservoir from which it would be taken by another pump and so on. Instances are recorded in which pumps raised 4,614,800 gallons per 24 hours, having pistons 24 inches in diameter and a stroke of 10 feet.

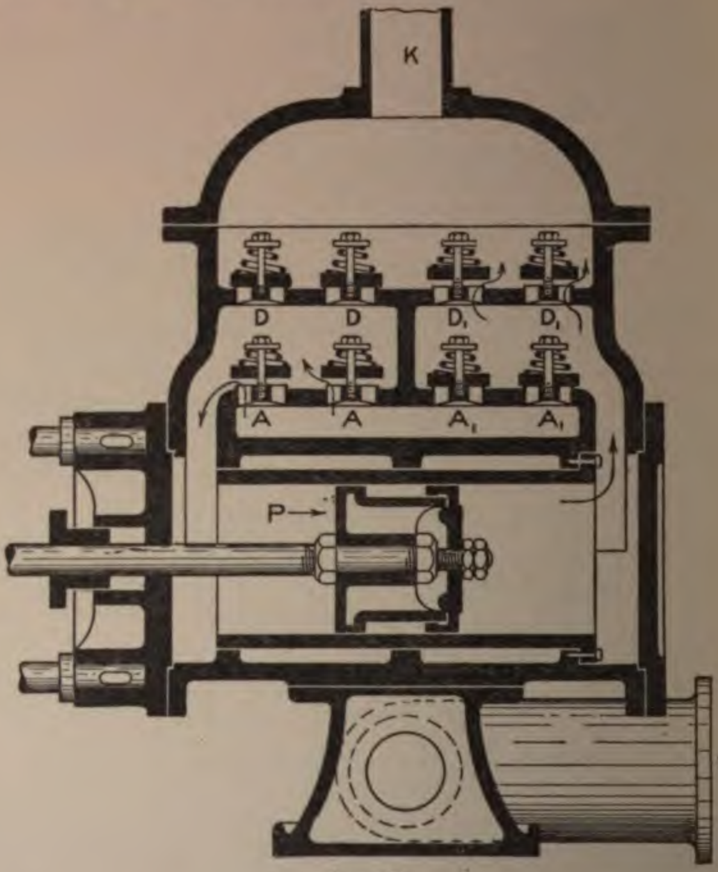

Fig. 16.

Forcing Pumps. For raising water to a height greater than can be conveniently overcome by lifting, or when the discharge is desired at a distance from the pump, it is better to use the forcing type. The simple principle of this type is shown in Fig. 3. There are, however, many modifications in common use. It is usual, if the lift to the pump be great, to install a foot valve at the bottom of the suction pipe, as well as to use admission valves to the pump chamber so that the suction pipe will be kept filled at all times, and the tendency for the water to drop out of the pump chamber, while the suction valve is closing, be removed.

The most common form of forcing pump is the double-acting piston type as seen in Fig. 16. As the piston P moves to the right, it will create a suction in the left-hand end of the cylinder, drawing in water through the valves AA and the suction pipe S. At the same time pressure will be exerted in the right-hand end of the cylinder and water will be forced out of valves D_1D_1, into the discharge chamber and up the pipe K. On the reverse stroke, water will be drawn in at valves A_1A_1 and forced out of DD. The piston must, of course, be packed water tight.

As in the case of lifting pumps, the volume to be raised and the speed at which the pump can be run determine the size of the piston; but the speed is usually greater than in the lifting type. The pump must not be placed over 20 feet above the level of the water which it is to raise, hence for a high head the greater part of the lift must be obtained by forcing against the head above the pump. It is a common rule that the travel of a pump piston should not exceed 100 feet per minute, and, taking the same problem as for the lifting pump this gives, $\frac{23{,}100}{100 \times 12} = 19.25$ square inches as the area of the piston. At the increased speed, the slip will be greater, hence it will be necessary to allow 5 per cent or an area of $19.25 \times 1.05 = 20.21$ square inches corresponding to a diameter of $5\frac{1}{16}$ inches.

The head would be the same, hence the total pressure per square inch would be the same as for the lifting pump, but the power would be increased. The total force on the piston will be $20.21 \times 86.60 = 1{,}750.1$ pounds. At 100 feet per minute this will require $\frac{1{,}750.1 \times 100}{33{,}000} = 5.30$ horsepower, which is less than before because the weight of the pump rod is not lifted at each stroke. If the rod be counterbalanced by a weight at the opposite end of a walking beam, the lifting pump will have a slight advantage owing to the smaller slip.

The pump shown in Fig. 16 is double acting, that is, it works on both strokes, but pumps, especially of the vertical type, are often made single acting to suck on the up stroke and force on the down; these have only half the capacity for the same size as the double acting.

The great difficulty with the piston is in keeping the packing tight or of knowing when it is leaking; it is also difficult to repack as the pump must be dismantled in order to get at the piston. For this reason the plunger pump is often preferred and is used either single acting with stuffing box around the plunger as in Fig. 3, double acting with two plungers as in Fig. 17, or double acting with one plunger as in Fig. 18. The advantage of this last over the piston is that for high pressures it is more easily kept tight, and for gritty liquids the wear is taken by the bushing which is more easily and cheaply replaced than a lining to the cylinder. The piston pump is more compact; but the plunger

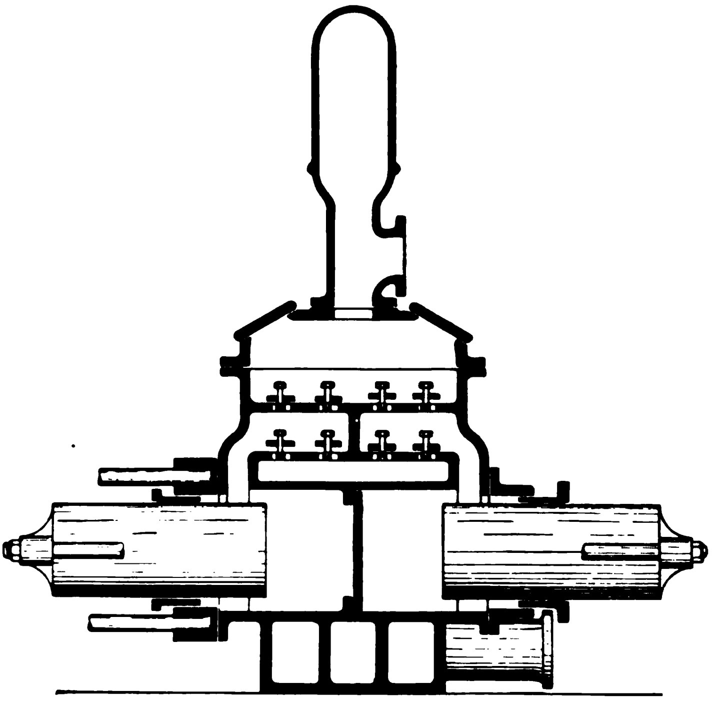

Fig. 17.

does not require a bored cylinder so that the first cost is not materially different.

The two-plunger pump with outside yoke is still larger than the single-plunger double-acting type but it can be easily repacked, can be kept tight against high pressures and any leaking is instantly detected. For these reasons, it is a favorite. The double-acting pump, not only has greater capacity, as above mentioned, but, on account of its continuous action produces a much steadier flow than the single-acting type, so that it is generally preferred.

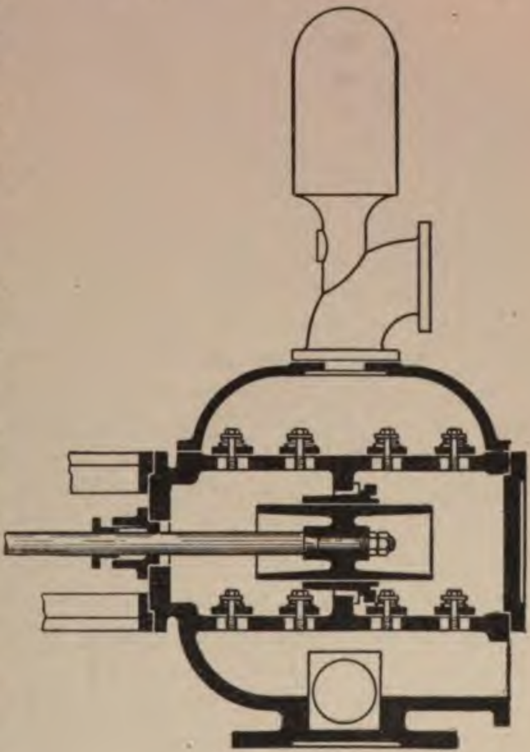

Fig. 18.

A modified form of Worcester's Engine, Fig. 1, is seen in the pulsometer or hydrotrophe, Fig. 19, which is still used to a considerable extent where extreme simplicity is desired. The ball B rolls so as to close first A′ and then A; with the ball in the position shown and the chamber D filled with steam, water will be drawn up through F by the vacuum caused by condensation of the steam. Meantime steam will enter D′ through A and force the water out through the check valve G. This will continue until the steam in D is all condensed, when the rush of the water, due to its inertia, will drive the ball valve B over against port A, thus reversing the action. It is entirely automatic and, as the machine is the acme of simplicity and may readily be made with large openings, it will handle dirty liquids with a minimum of attention. Its usual heat efficiency is 1.2 to 1.5 per cent, but this is not as objectionable as it seems, since small reciprocating steam pumps often do little or no better. C is a suction air chamber connected with the opening E to equalize the flow of water.

VALVES.

Pump valves must be so made that they will open and close quickly and fully with little friction, so that there shall be no obstruction to the passage of the water, yet little leakage of water past the valves after the reversal of motion of the piston and before the valves have seated. Quick opening requires a light valve with slight motion, but quick closing demands either a heavy valve or a spring to hasten its action. In older pumps it was the custom to use one large valve with a lift sufficient to give the required passage; the valve was then heavy enough to close of its own weight, but was clumsy and hard to fit to a seating. In modern practice the required area is divided among several small valves so that each one is easily and cheaply renewed in case of accident or wear, and quick closing is obtained by the use of springs on the spindles of the valves.

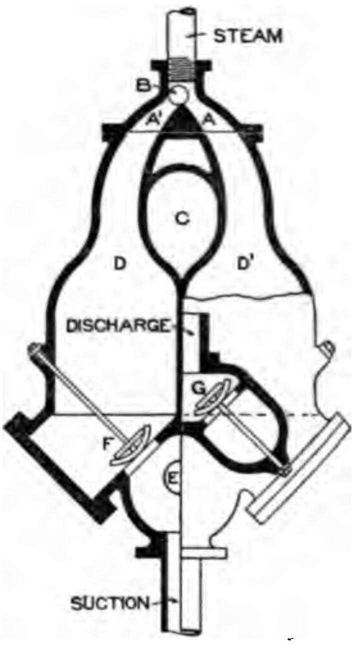

Fig. 19.

The natural classification of valves is by the motion and by the method of securing a tight joint; according to the motion there would be division into flexible, hinged, poppet and ball; according to the seating, into cushioned and ground.

The Flexible valve is the oldest type, and is, in some ways, the simplest. It is generally made of rubber, as this material gives the greatest flexibility with the best seating. The valve is made as a solid disc, the opening being obtained by the flexibility of the valve itself, and is usually of the style shown in Fig. 20. The seat is made with radial grids to take the pressure of the water, the openings between the bars being made equal to the thickness of the disc; this thickness depends in turn on the diameter of the disc, and is often made as given in the following table:

Diam. of disc. Inches.	Thickness of disc. Inches.	Diam. of hole in center. Inches.
2	$\frac{3}{8}$	$\frac{1}{2}$
$2\frac{1}{2}$	$\frac{7}{16}$	$\frac{1}{2}$
3	$\frac{1}{2}$	$\frac{9}{16}$
$3\frac{1}{2}$	$\frac{5}{8}$	$\frac{11}{16}$
4	$\frac{5}{8}$	$\frac{11}{16}$
$4\frac{1}{2}$	$\frac{3}{4}$	$\frac{13}{16}$
5	$\frac{3}{4}$	$\frac{13}{16}$

The valves of this type most commonly used are the 3-inch and the $4\frac{1}{2}$-inch as the larger sizes are not found durable. The 3-inch is the best for ordinary use. The hole in the center is made $\frac{1}{16}$ to $\frac{1}{8}$ inch larger than the spindle to allow of free motion; to avoid sudden bending of the rubber, the guard is placed to give the disc a chance to rise about $\frac{3}{16}$ inch. When it has risen so far, it bends around the guard and thus gives a free opening for the passage of the water. The guard should have a diameter equal to that of the disc less twice the thickness of the disc, and the radius of curvature should be equal to the diameter of the disc. This type of valve is not well suited for high pressures, 250 feet head being about the limit for the ordinary style. If, however, there are vanes arranged below the disc so that a rotary motion is given to the valve, it is found that there is no difficulty in keeping the valve tight for heads up to 490 feet. For these pressures, it is not uncommon to use discs of a thickness up to an inch, but only for large sizes. The lap of the valve over the edge of the seat should be from $\frac{1}{4}$ to $\frac{1}{2}$ inch according to the thickness of the disc and the pressure to be carried.

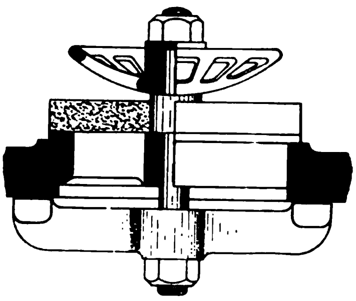

Fig. 20.

Leather valves have been used to some extent in the form of a simple flap fastened at one side and free to rise at the other; this makes the simplest form of hinged valve and, when weighted with a metal disc on either side, has been much used for small hand pumps. It is not suitable for severe service.

The Hinged valve, as its name implies, is made to swing about a pivot at one side, but should be designed to lift from its seat before it begins to swing. The disc is made of metal but often with a facing of leather or rubber for slow speeds; for high speeds these linings will not stand the wear. The lift should be about $\frac{1}{8}$ to $\frac{1}{4}$ inch before the valve begins to turn about the fulcrum. The angle to which the valve lifts is usually made 30 degrees, and should never be over 60 degrees, in order to ensure quick opening and closing. The motion is limited by a stop on the seat or on the disc of the valve as seen in Fig. 21. The hinged valve is slow in action and is not suitable for thick liquors or high pressures. In designing, the area allowed should be as follows:

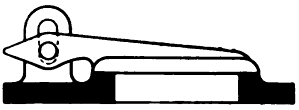
Fig. 21.

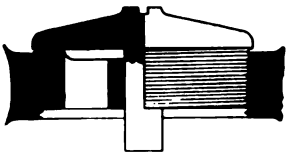
Fig. 23.

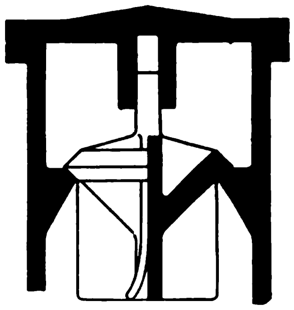
Fig. 22.

Piston speed, feet per minute	100	125	150	175	200
Area of waterway, per cent of plunger area.	40	50	60	75	100

For higher speeds or for high pressures, it is best to use some form of positively driven valve, and, if such liquors as sewage or syrups are to be handled, the areas found from the above table should be increased about 50 per cent.

The most common form of valve in use at present is the **poppet** which rises straight up from the seat and gives a free opening with a small motion. The seat is made either flat or at an angle of 45 degrees as the designer may choose, the beveled

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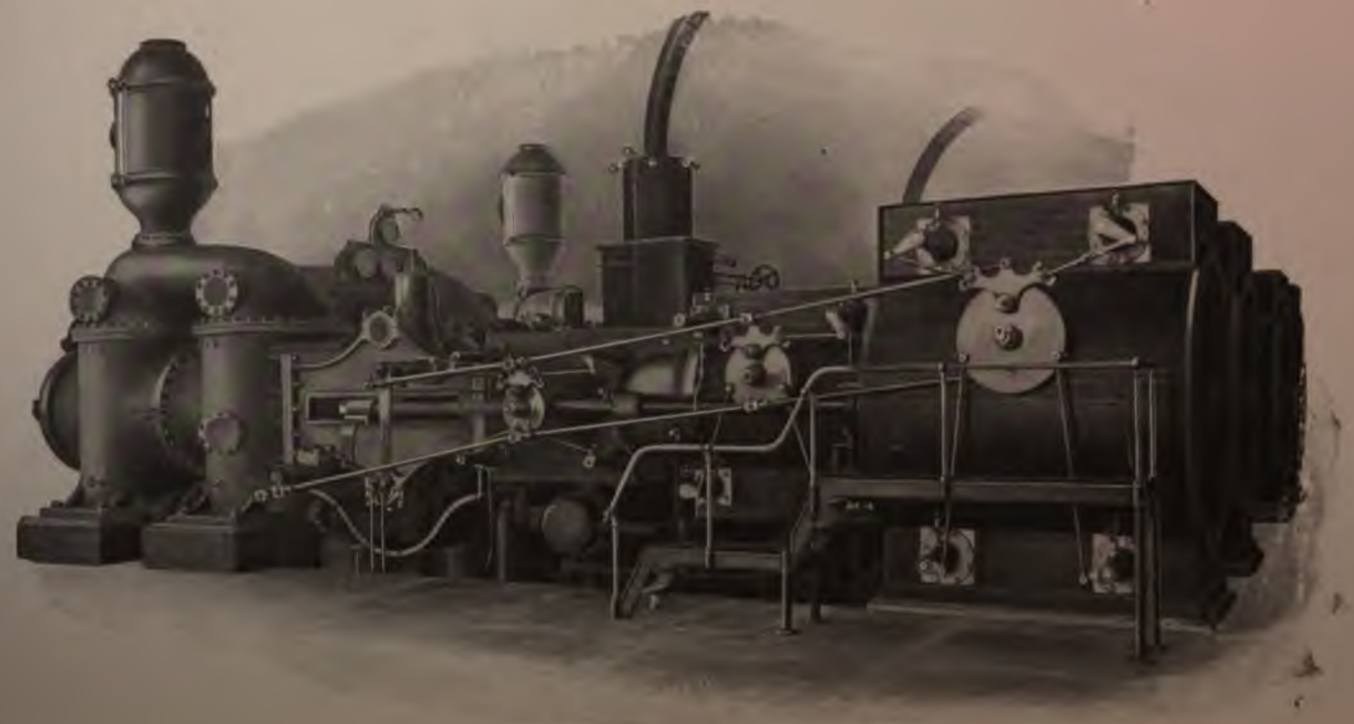


WORTHINGTON HIGH DUTY TRIPLE EXPANSION PUMPING ENGINES.
Mt. Royal Pumping Station, Baltimore, Md.

seat being more difficult to construct but retarding the flow of water less than the flat seat which necessitates a double turn in the current. The width of the beat or edge of the seat against which the valve rests is made $\frac{1}{4}$ inch for large valves and $\frac{1}{16}$ inch for small ones. The flow of the water through the valves should be at a velocity of not over 200 feet per minute, and the lift must be so proportioned that the passage by the valve will be as large as the area of the valve opening. A valve with flat seat need not have over $\frac{1}{4}$ inch lap even for heavy pressures, but the joint must be carefully made to avoid leakage.

A common form of **mitre valve** is shown in Fig. 22 and of **flat seat** in Fig. 23. The vanes on the bottom of the disc which keep the valve centered when it rises are often given an inclination of $\frac{1}{2}$ inch in 6 inches so that the rush of the water will give the valve a rotary motion, removing all dirt and keeping the wear on the beat even. For the flat beat valves this is not always possible as they are closed by a spring and the friction prevents them from revolving.

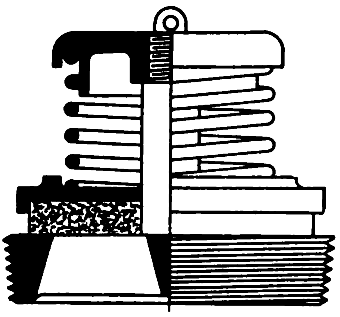


Fig. 24.

In order to give an area by the valve equal to the area of the seat, the lift must be one quarter the diameter of the seat opening. For heavy pressures this would make too large a lift, as the slip on closing would be excessive; for this reason the lift is made not over $\frac{1}{4}$ inch and the number of valves increased as may be necessary. The seat is usually made separate from the valve deck and screwed into place; when this construction is used, the guide for a valve (if there is one) should be made a part of the seat so that the valve is self contained. The guides may be in the form of wings on the bottom of the valve disc, a spindle running through a hole in the seat or a spindle projecting upward through the valve; the last being most common.

The discs may be of metal or hard rubber. For hot liquids metal must be used, but for cold liquids hard rubber or composition is more common, usually with a metal cap to keep the disc in shape. The spring used for closing the valve should be cylindrical rather than conical, as the strain on the latter form comes largely at the small end of the spring and the wire is likely to break there. A design to be recommended is that of Fig. 24 which is described by Barr; see "Pumping Machinery," p. 57.

Double beat valves and those with multiple ports are not usually necessary but are sometimes used for large work.

Ball valves are often used for low pressures. For these the diameter of the ball is made 1$\frac{1}{3}$ times that of the beat and a cage is provided so that the ball shall always be kept central. The ball is of gun metal usually with a rubber casing or, for cold water, sometimes wholly of rubber. They are common in pumps used for mines and oil wells and often in connection with cup leather packings for the piston. If the water is gritty or has impurities, the valve seat should be raised above the deck so that there will be room for the sand to settle below the seat, as seen in Fig. 25.

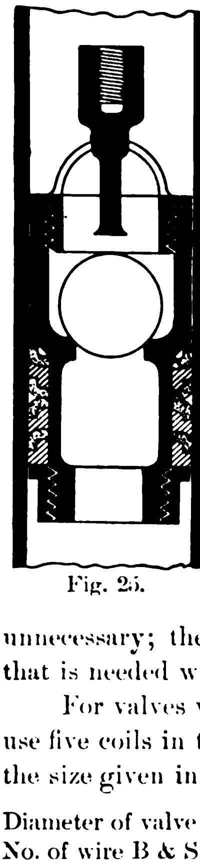


Fig. 25.

In all valves which have metal for both discs and seats, it is important that they should both be of the same material, as otherwise there is likely to be galvanic action which will cause rapid deterioration. Usually, however, it is better to use the valve with a separate disc of composition as this avoids all possibility of electrical action and makes the refacing of the valve unnecessary; the replacing of the old disc by a new one being all that is needed when the valve becomes worn.

For valves which are to be returned by a spring, it is best to use five coils in the spring and to have the wire of spring brass of the size given in the following table:

Diameter of valve inches	2	2½	3	3½	4	4½
No. of wire B & S	12	12	10	10	8	8

In this style, it is well to use for the guiding spindle a stud screwed solidly into the valve seat or made a part of the casting, and fasten the valve by a nut at the top of the stud, secured by a pin. This is usually better than to use a stud screwed into the valve seat. If the latter is used, it is likely to work loose and may cause much damage before the trouble is discovered; it is also more difficult to remove when repairing the valve.

The material for the valve depends on the liquid to be handled. For acids or liquors of that nature, it is best to use wood, although it is not durable, yet it will last better than any form of metal; for salt, petroleum products, and strong alkalies, gun metal is the best; for all ordinary uses, however, cast iron is good enough, and if used with composition discs there will be no trouble from rusting fast even if the pump is idle for considerable periods.

With respect to valves for large pumping engines, they are best made of double beat type, and usually of the "Cornish" form. For this a design used by Mr. A. F. Nagle has proven very satisfactory; it is shown in Fig. 26. The features embodied in this design are a small width of beat to avoid any possibility of sticking and to get rid of surface on which the pressure of the water cannot act to open the valve; a diameter large in comparison with the lift so that the velocity with which the water comes to the opening shall be small; a shape which avoids all sharp curves and changes of direction and all possibility of air pockets. The valve has been found to embody all these qualities, to work noiselessly even at high speeds, and to follow the motion of the piston almost exactly.

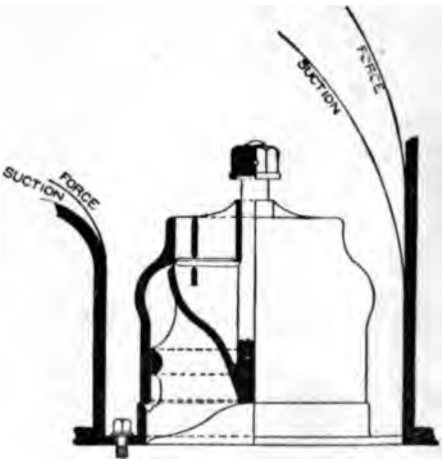


Fig. 26.

DESIGN AND CONSTRUCTION.

The essential parts of a reciprocating pump are inlet valves, a cylinder, a piston or bucket and outlet valves. The purpose of each is obvious. However, in order to get the best results certain points must be considered in the arrangement and construction of these parts. Some of these have already been mentioned in the description of valves. Admission and outlet valves are usually of the same construction but sometimes differ in size, the outlet valves being smaller and more numerous so that the lift may be less and the slip under high pressures reduced. Valve decks are usually arranged, one for the inlet and one for the outlet valves; into these decks are screwed or bolted the valve seats, as already shown in Figs. 20--24, the valves extending above into a valve chamber as shown in Fig. 16. The valves should have space enough between them and between the outside valves and the walls of the valve chamber so that the area for the passage of the water shall equal that through the valve openings. Generally, considerations of strength of the valve deck also demand as wide spacing as does the necessary water way.

The design of the **cylinder** depends entirely on the kind of pump; the considerations involved having already been mentioned. For a small and compact machine, the piston type is the best and this calls for a smoothly-bored barrel. In order that this may be easily renewed, it is usual to make the bored portion as a lining which fits an outer casting so that when worn by grit or long use, the lining may be renewed without remaking the whole water end. Such a construction is shown in Fig. 16.

If there is much sand or dirt in the water, it is usually better to use some form of plunger pump, as the round-turned plunger is much cheaper to renew than the bored-barrel lining; also the cylinder will be cheaper as there is little boring to be performed. The difficulty of an inside packed plunger has been mentioned and also the alternative of a double plunger, outside packed. (See Figs. 17 and 18). In spite of the difficulty of ascertaining and stopping leakage past the piston, and the expense of boring and reboring or relining the cylinder, the piston pump is used, except for high pressure, more than any other form on account of its compactness.

The bucket is rarely used except in vertical pumps and then almost entirely for mine or well purposes. It is of the form of Fig. 25 with possibly the clack or hinged valve in place of the ball. The outside of the bucket is packed by cup leathers or by hemp packing, the same as a piston, or it may simply have grooves turned in the outside to form a water packing. The barrel is often simply a brass pipe, bored to make a fit, and screwed to the end of the vertical pipe so that it may be easily renewed. In the case of deep wells, the bucket should be made with a long bearing surface so that it may the more easily keep a water-tight joint and may act as a steadier to keep the pump rod in line.

The **piston rod** for a pump is made much larger than considerations of strength would seem to demand, in order that there may be no vibration or deflection, as these would make it almost impossible to keep the stuffing box from leaking. Theoretically the rod for a long-stroke pump should be larger than that for a short-stroke of the same diameter; but, actually, the margin of strength is so great that the same size rod will answer for both. Allowance must be made in all cases for the reduction in diameter necessary to fasten the piston or plunger to the rod. This may be done by using a tapered end fitting a tapered hole in the body of the piston or by turning down the end of the rod and letting the piston bear against a shoulder; the latter method is the better. Usually a nut holds the piston in place, the nut being in turn secured by a lock nut or split pin through the end of the rod. Various modifications of these methods are of course used according to the fancy of the designer.

The diameters of piston and corresponding rod for a rod of cold rolled steel, tensile strength 65,000 pounds, a factor of safety of 10 and a pressure of 150 pounds are given in Table IV.

TABLE IV.

Piston diam. Inches.	Rod diam. Inches.	Diam. of rod end, Inches.
4	1 3/8	1 1/8
6	1 5/8	1 3/8
8	1 7/8	1 1/2
10	2 1/4	1 5/8
12	2 3/8	1 3/4
14	2 1/2	2

The **water end** of the pump is necessarily long, as the piston must be of such length that it can be packed, and usually with some kind of soft packing such as flax, hemp or leather. Fig. 27 shows the detail of a piston designed for use with square flax packing; the body is fastened to the piston rod by the nut A, the packing laid in place, and the follower forced up by the nut B which is, in turn, secured in place by the lock nut C. For large sizes, the design is the same except that the follower is set up by a number of nuts near the edge screwed onto stud bolts.

The leather-packed piston is made as shown in Fig. 28. The packing is made by pressing sheets of wet leather into iron forms and allowing them to dry there, after which the edges are finished, The radius of the corner must be large, so that the leather will not be injured in the pressing process, about ½ to ¾ inch being sufficient. The diameter of the disc from which the cup is formed need not be more than 1¼ to 1⅜ inch greater than that of the piston, as there is no object in having the lip of the cup longer than just sufficient to make a tight joint.

Less common forms of piston packing are the metal ring sprung into place and the series of grooves. For the former, the ring should be made about ⅛ inch larger than the piston for a 12-inch piston; other sizes in proportion. For the groove packing, the grooves are best made about ⅜ inch deep by ¼ inch wide. If soft packing is used, the length of a piece cut for a ring should be somewhat less than that needed to have the ends meet when placed around the piston body in order to allow for the swelling of the packing as it becomes wet. One rule is to make the space between ends equal to the width of the packing.

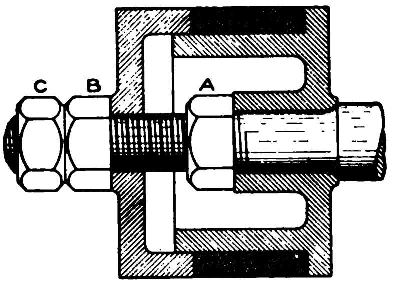


Fig. 27.

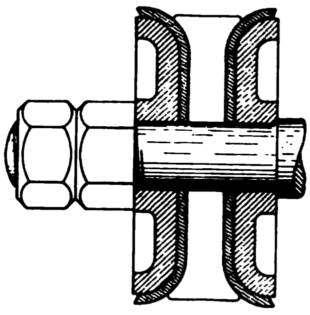


Fig. 28.

For a plunger, a hollow casting is generally used; the only requirement being that the thickness shall be sufficient to withstand the pressure against which the pump acts. The length must, of course, be equal to the stroke plus the length of the stuffing box and an amount sufficient to ensure that the head of the plunger will never strike the gland. A plunger is sometimes used with an open end and the partition set back into the interior of the plunger, but this is not as strong a construction as the closed-end type and is more expensive to make.

With single-cylinder pumps it is customary to use an air chamber on the discharge to steady the flow of the water and prevent shock, but for those having several cylinders this is not considered necessary. Even if the motion is slow, and the pressure against which the pump works is great, it is better to use the air chamber even with multiple cylinders, and it is often advisable for fast running pumps or those with a long suction pipe to use an air chamber on the suction side as well. The volume of the discharge chamber should be three to four times that of the piston or plunger displacement per stroke, and for the suction chamber twice such displacement if the pump is single. For duplex, $\frac{1}{3}$ to $\frac{1}{2}$ less will answer. The neck of the chamber should be long and narrow so that the air will not easily escape, and the flow of water into and out of the chamber will be somewhat retarded. For small sizes the chamber is made of copper in a standard form as seen in Fig. 29, the dimensions being about as follows:

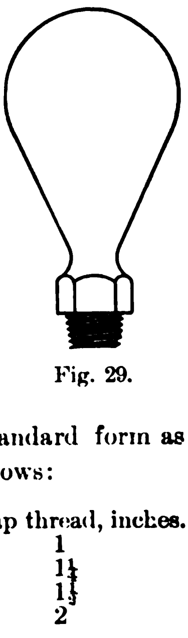


Fig. 29.

Diam. inches.	Height, inches.	Pipe-tap thread, inches.
6	10	1
8	14	1¼
9	15	1½
10	16	2

For larger sizes a casting is used with straight sides and a hemispherical top as seen on Fig. 17. For this style a common proportion is to make the height three times the diameter and the diameter of the neck one-third that of the chamber proper.

The air chamber on the discharge should be placed at the highest point of the valve chest and above the delivery opening so that the air will not tend to slip out with the water. Even then, the air will be gradually absorbed by the water, and provision must be made for renewing the air cushion either when the pump is not in use by admitting air through a cock and allowing some water to escape from the valve chest, or continuously by an automatic pump.

The suction air chamber should be so placed that the stream of water flowing to the pump may cushion against the air in it without changing its direction abruptly. Two positions which fulfill this condition are shown in Fig. 30. If it is impossible to place the suction chamber in such a position, the capacity should be increased considerably, the amount depending on the speed at which the pump is to be run.

In designing the valve chest, flat surfaces should be avoided, as they are not adapted to resist pressure. A rounded or oval surface gives greater strength and will more easily conform to the outline presented by the valve studs and the top of the chest. A good design is shown in Fig. 16.

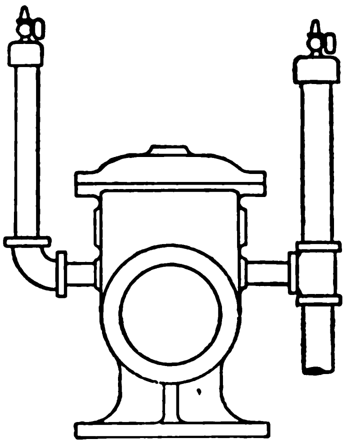


Fig. 30.

Clearance is the name given to the space at the end of the cylinder into which the piston or plunger does not travel. It is not, as is the case with the steam engine, a source of loss, hence it is advisable to provide a generous amount so that there will be a place for grit or foreign matter to settle, and no possible chance of the piston striking the cylinder head.

The ports or valve openings and the passages from the valve chests to the cylinder should be large enough so that the velocity of the water when the pump is working at its greatest speed will be not over 300 feet per minute. The ports should be short and direct to avoid friction, and if possible should be so arranged that the water passes into, through and away from the pump without changing the direction of its motion. This last condition usually conflicts with the necessity of placing the valves so that they are readily accessible and is, therefore, disregarded by many makers.

The stuffing-box for rods 1 inch or less in diameter is made with a cap to screw over the end of the box and forces in the gland as in Fig. 31. For larger sizes the gland is forced in by nuts screwed on stud bolts which pass through a flange on the gland. See Fig. 32. The gland and box may be bushed with brass as shown, or made of solid iron. The box should be made deep enough to allow four rings of packing and should preferably have the bottom and the end of the gland chamfered in order to force the packing against the rod and make the joint more secure.

The frame or body of the pump is to hold all parts together and keep them rigidly in position. With this end in view, it pays to use enough iron to make the frame massive, yet it should be so distributed as to be of the most use. The standards or legs should be of good length so that the pump may stand well away from the foundation and be accessible. The feet should have a large surface to secure stability and good bearing. For pumps which are to work against high pressures, round chambers connected by round passageways should be used for the valve chambers. The valve chambers should be so arranged that the valves or seats may be easily removed and replaced, a convenient arrangement being that of Fig. 16 where the inlet valves are directly under the outlet valves, hence can be readily examined Details of such an arrangement as used in the Cameron and Davidson pumps are seen in Figs. 33 and 34 respectively.

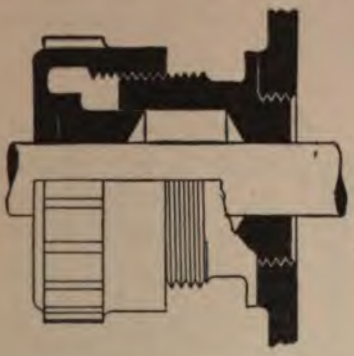


Fig. 31.

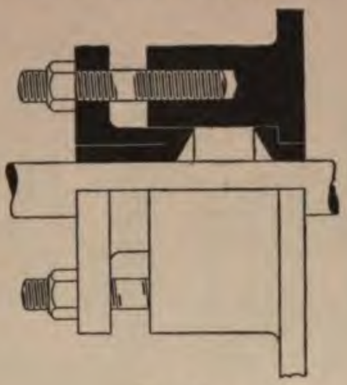


Fig. 32.

The arrangement of the parts of a pump is the test of a designer's skill. Air pockets must be avoided in the cylinder or clearance spaces, as otherwise the pump will waste much of its effort on the air thus caught. The passage through the cylinder must be so designed that the water leaves at the highest point of the chamber and all recesses in which air might be caught must be carefully avoided. Air pockets in the discharge valve chamber are not serious, but in the inlet valve chamber they will result in lost motion.

Almost all small horizontal pumps are arranged with both the inlet and discharge valve chambers above the cylinder, as this makes all valves readily accessible, and gives a compact water end. Unquestionably smoother action and a more efficient pump would be obtained if the admission valves were placed below the cylinder so that the water need not reverse its direction of flow while passing through the pump; but it is a case for judicious compromise, and the common arrangement gives good service so long as the speed of working is slow. Nevertheless, it is well to keep the better arrangement in mind, in which the suction enters at the bottom of the pump and the discharge leaves at the top.

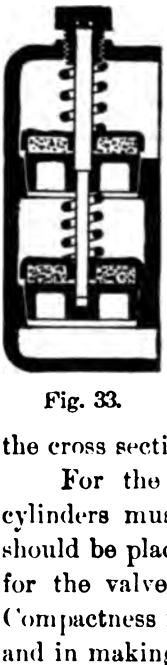


Fig. 33.

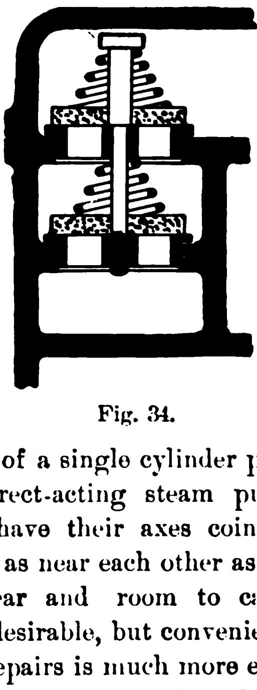


Fig. 34.

The suction pipe usually comes in at one side, and the discharge leaves directly above it on the same side, as shown in Fig. 35, or the side opposite. Fig. 35 is the cross section of a single cylinder pump.

For the direct-acting steam pump, the steam and water cylinders must have their axes coincident. The two cylinders should be placed as near each other as is consistent with provision for the valve gear and room to care for the stuffing boxes. Compactness is desirable, but convenience in caring for the pump and in making repairs is much more essential.

At the lowest point on each end of each cylinder provide a drain cock by means of which all water may be drawn off when the pump is shut down in order to prevent rusting or pitting and to avoid danger of freezing in cold weather.

The size of the piston or plunger and length of stroke are determined by the capacity desired. The allowable speed of piston is often stated as 100 feet per minute, but it is better limited to 60 double strokes per minute, as the determining factor is really the time needed for reversal and changes of valves at the end of the stroke. For small pumps the limit might be made 100 double strokes per minute, but the smaller number is better. At 60 double strokes or 120 single strokes per minute the piston speed in feet per minute will be:

$$\frac{l \times 120}{12} = 10\,l$$

where l is the stroke in inches; and for 100 double strokes the speed will be $\frac{10}{6}$ times the above value or $16.7\,l$. For pumps of over 6-inch stroke this higher limit is not advisable.

Table V gives the capacities of various sizes of pump cylinders at 60 double strokes per minute, without allowance for slip.

From Table V can be seen directly the capacity of any size pump at a speed of 60 strokes per minute, or the diameter and corresponding length of stroke needed to move any given number of gallons per minute. To find the capacity at any other speed, divide the given capacity by 60 and multiply by the number of double strokes at which the pump is to run. Thus to find the capacity of a pump 3 inches diameter by 4 inches stroke at 80 strokes; the capacity at 60 strokes is 14.7 and at 80 it will be

$$\frac{14.7}{60} \times 80 = 19.6 \text{ gallons per minute.}$$

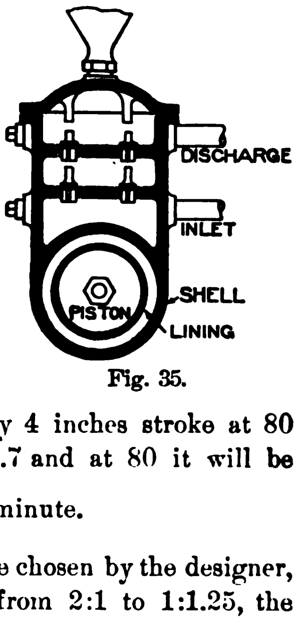


Fig. 35.

The ratio of stroke to diameter may be chosen by the designer, the value in standard designs running from 2:1 to 1:1.25, the more common being 3: 2 and 1: 1.

The first value to be found is the amount of water to be handled per minute, and this will usually be determined by the work for which the pump is to be used. The allowance for "slip," that is, the loss due to slow closing of the valves and leakage must then be added before the size of the water end can be settled.

The slip depends on the style of valve used, the size of pump

TABLE V.

CAPACITY OF PUMPS IN GALLONS PER MINUTE AT 60 DOUBLE STROKES PER MINUTE.

Diameter	STROKE.														
	2	3	4	5	6	7	8	9	10	12	14	16	18	20	24
1	.0.81	1.21	1.63	2.02	2.42	2.85	3.26	3.68	4.10	4.90	5.70	6.52	7.36	8.20	9.80
2	3.26	4.89	6.52	8.15	9.78	11.41	13.04	14.67	16.30	19.56	22.82	26.08	29.34	32.60	39.12
2½	5.06	7.63	10.18	12.72	15.27	17.81	20.36	22.90	25.45	39.54	35.63	40.72	45.81	50.90	61.08
3	7.34	11.01	14.68	18.35	22.02	25.69	29.36	33.03	36.70	44.04	51.38	58.72	66.06	73.40	88.08
3½	9.95	15.00	20.00	25.0	30.00	35.00	40.00	45.	50.	60.	70	80	90	100	120
4	13.1	19.6	26.2	32.6	39.2	45.8	52.2	58.9	65.3	78.4	91.6	104.4	117.8	130.6	156.8
4½	16.6	24.8	33.0	41.3	49.5	57.8	66.1	74.4	82.5	99.0	115.6	132.2	148.8	165.0	193.0
5	22.0	30.6	40.8	50.9	61.1	71 3	81.5	91.6	101.8	122.2	142.6	163.0	183.2	203.6	244.4
6	29.4	44.0	58.8	73.4	88.0	103.	117.6	132.3	146.8	176.0	206.	235.0	264.6	203.6	352.0
7	39.9	60.	79.8	100.	120.	140	160	180	200	240	280	320	360	400	480
8	52.2	78.4	104.4	130.8	156.8	183.	208.8	234.8	261.6	313.6	366.	417.6	469.6	523.2	627.2
9	66.1	99.2	132.2	165.	198.4	237.	264.	297.	330.	396.8	474	528	594	660	793
10	81.5	122.4	163.	204.	244.8	286.	326.	367.	408.	489.	572	652	734	816	978
12	117.6	176	235.2	293.6	352.	412.	470.	529.	587.	704.	824	940	1058	1174	1408
14	160.	240	320.	400.	480.	560.	640.	720.	800.	960.	1120	1280	1440	1600	1920
16	209	313	418	523	626	732	836	939	1046	1252	1464	1672	1878	2092	2504
18	264	397	528	660	794	948	1056	1188	1320	1588	1896	2112	2376	2640	3176
20	826	489	652	816	978	1144	1304	1468	1632	1956	2288	2608	2936	3264	3912
22	895	591	790	988	1180	1380	1580	1780	1978	2360	2760	3160	3560	3956	2720
24	470	704	910	1174	1408	1648	1880	2116	2348	2816	3296	3760	4232	4696	4832

and the speed at which it runs. Approximate values are shown in table VI.

TABLE VI.

Class of Pump.	Slip in Percent of Volume Pumped.	
	At high speed.	At low speed.
Small Centrifugal	75	60
Medium "	50	40
Fire Engines	40	30
Large Centrifugal	25	15
Lift and Drainage	15	10
Mine and Deep Well Pumps	8	5
Waterworks	6	4

We can now determine the size of a pump to move a given volume of water. Suppose, for example, that it is required to force 200,000 pounds of water through a condenser per hour. This, at 8.338 pounds per gallon, would be 23,987 gallons per hour, or 400 per minute, if there were no slip; but for a common lift pump we must allow 10 per cent so that the capacity must be for $400 \times 1.10 = 440$ gallons per minute. From table V this would require a 10×12, a 9×14 or an 8×18; the 10×12 would be the most common proportion.

The area of valves should be such that the velocity of the water through them will not exceed 250 feet per minute; for 440 gallons, the volume would be $\frac{440 \times 231}{1728} = 59.8$ cubic feet. At 250 feet per minute, the valve area $= \frac{58.8}{250} = .2352$ square feet, or practically 34 square inches. The area of 3-inch valve is 7 square inches, so that the five valves would be sufficient. The circumference is 9.42 inches; this gives a lift of $\frac{34}{5 \times 9.4} = .723$ inch, an amount perhaps not too great for smooth action at the low pressure of a condenser pump; but it would be better even for this service to use twelve 2-inch valves giving a lift of .45 inch.

To find the power required, it is necessary to know the pressure against which the pump is to act both for suction and forcing. Assume this to be, in the present case, 5 feet of suction head and 5 pounds pressure due to the friction in piping and condenser tubing; the total pressure will then be 7.16 pounds per square inch, and on the 10-inch piston the total force would be 78.54 × 7.16 = 562 pounds. The pump is to make 120 strokes per minute, each stroke being 12 inches or one foot long, so that the work per minute would be 120 × 562 = 67,440 foot pounds, and the power 67,440 ÷ 33,000 = 2.04 horsepower provided there were no friction. It is customary to allow 25 per cent for friction in pumps, which would increase the power required to 2.04 × 1.25 = 2.55 horsepower.

To find the diameter of steam piston needed, the steam pressure must be known and the foregoing process can then be reversed. Assume the pressure to be 80 pounds; the work per minute is 2.55 × 33,000 = 84,000 foot pounds, which, at 120 feet per minute would require a force of 700 pounds, and, at 80 pounds per square inch an area of $\frac{700}{80} = 8.75$ square inches, corresponding to about a 3⅜-inch diameter. Usually the steam and water ends are made much more nearly the same size than this would indicate and the steam throttled between the boiler and the steam end of the pump, so that the pump may be adaptable to a wide range of conditions.

The parts of a pump should be proportioned to withstand the forces which are to come on them, not only without danger of breaking, but without bending. For the parts which are to be of cast iron, such as cylinder, valve-chests and frame, the consideration which decides the dimensions is often the thickness of metal which will cast well; while for the piston it is the length which will give a good bearing surface on the cylinder to resist wear, and a tight joint to prevent leakage. These points are largely matters of experience and good judgment, but some ideas can be given as to common practice.

For a packed piston, usually 4 rings of ¾-inch square packing are used. Common values of rod diameters are given in Table IV. In designing the body and follower of the piston, it should be remembered that the less weight the better so long as the strength is sufficient; but a piece of cast iron less than ⅜-inch thick seldom casts well in any complicated casting.

For the cylinder, the same equation may well be used for both steam and water ends. Whitham gives, allowing for strength, rigidity and possible reboring: $t = .03\sqrt{P\ D}$ where P is the maximum pressure in the cylinder in pounds per square inch and D the diameter in inches; *t* is of course the thickness of the cylinder walls. The length of the cylinder will be the length of stroke plus the thickness of piston and fastening nuts plus twice the clearance at one end which should be at least $\frac{1}{4}$ inch. The clearance should be counterbored to leave the length of the bore somewhat less than the length of stroke plus the length of piston. The soft packing or piston rings should not, however, be allowed to run into the counterbore. An average of various formulas for the thickness of cylinder heads and flanges as given by Kent, is $t = .00036\ P\ D + .31$ inches. The flanges on the cylinder are made of the same thickness as those on the cylinder head.

For large cylinders it is usual to support the head by ribs running from the center to the circumference, though some designers consider this bad practice. The flange through which the bolts pass is made $\frac{1}{3}$ thicker than the thickness of heads given by the above formula. To avoid springing of the flanges, cylinder-head bolts should be so spaced that the distance on centers will be not over 4 to 5 times the thickness of the flanges. The diameter should be such that the stress in the bolts will be less than 5000 pounds per square inch. If N is the number of bolts and *d* their diameter,

$$N \times \frac{\pi d^2}{4} \times 5000 = \frac{\pi D^2}{4} P, \text{ and simplifying,}$$

$$d = D\sqrt{\frac{P}{5000\ N}}$$

The area of inlet and discharge ports and pipes should be at least equal to that of the valves.

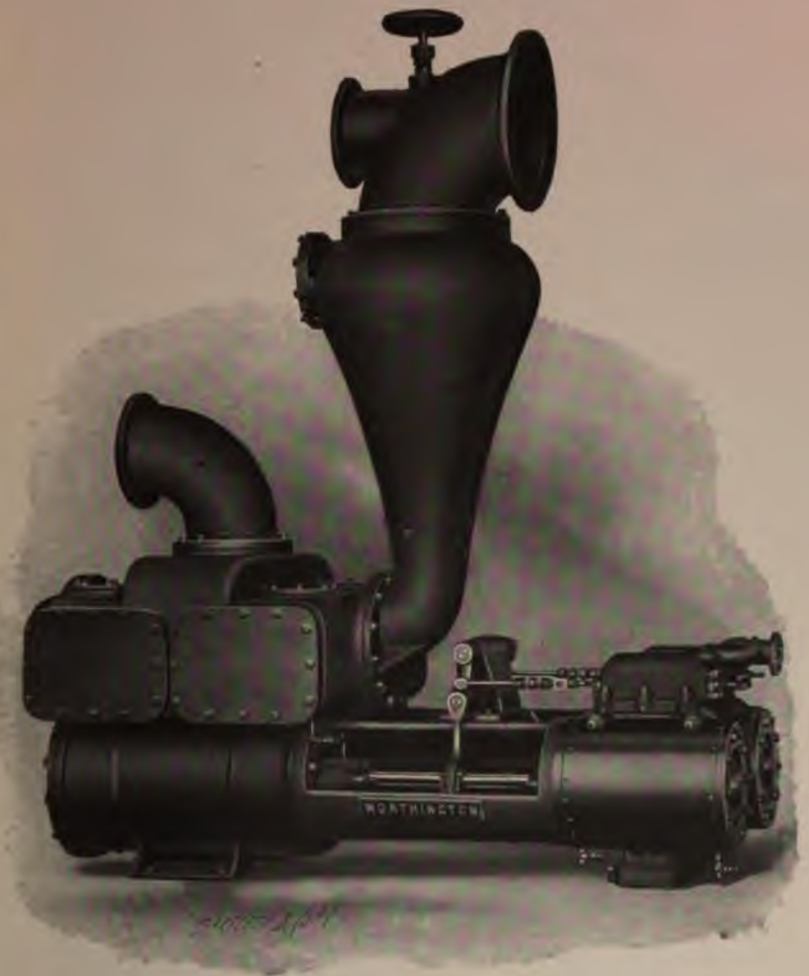
The thickness of the walls of the valve chambers is usually a little greater than that of the cylinder walls. For high-pressure pumps it is best to give these chambers as nearly as possible a cylindrical form in order to secure the greatest strength for a given weight of material.

For the frame, it is impossible to give any rules or suggestions except that the student should get catalogues from the prominent makers and study them to see what has been found satisfactory.

For proportioning the driving end of a pump, whether steam, belt or motor driven, the ordinary rules for the kind of machinery involved apply. However, it should be remembered that the parts are subjected to severe shock on the reversal of the pump, hence a factor of safety as high as 15 should be used.

Where pumps are required for special service, the amount of water to be pumped per hour is generally fixed by the conditions of the service; but for a few cases the method of determining that amount can be definitely given. For a **boiler-feed pump**, it is necessary to know the horse-power of the boilers to be cared for by the pump. One boiler horse-power will call for the handling of 30 pounds of water per hour, and the pump should be specified accordingly with an allowance for good measure. For an air pump to remove the air and condensed steam the amount of fluid to be handled is difficult to estimate, hence, a common rule is to make the volume of the double-acting air-pump cylinder $\frac{1}{20}$ that of the low-pressure cylinder of the engine which it is to serve. The double-acting circulating pump has a volume about $\frac{1}{35}$ that of the low-pressure cylinder, or it may be figured from the horse-power of the engine, assuming the steam consumption at 25 pounds per I. H. P. per hour, and the cooling water at 30 pounds per pound of steam. Of course for accurate calculation, the steam consumption would vary with the size and type of engine, but the above will give safe average values.

Fire pumps are designed with special care to meet the requirements of the insurance companies. Stated briefly these are: Ability to start instantly after long disuse; must be duplex, with cross-operated valves; should preferably be of plunger pattern; must be brass-fitted throughout; designed to carry a water pressure of 320 pounds; suction valve area should be not less than 50 per cent of plunger area for 10-inch stroke and 56 per cent for 12 inch; discharge valve area should not be less than $\frac{2}{3}$ the suction-valve area; valve springs should be cylindrical, not conical, and held at the ends in a groove; studs to be so designed as to always allow a lift $\frac{1}{6}$ of the valve diameter; valve seats should be of gun metal held in the deck by a taper thread, or a smooth



WORTHINGTON AIR PUMP AND JET CONDENSER.
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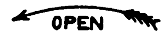
taper bore forced in, having the lower edge turned over; least area of exhaust passage should be 4 per cent of piston area; admission ports should be not less than $2\frac{1}{2}$ per cent of piston area; clearances should be as small as possible; valve tappets should be non-adjustable; cushion valves controlling a by-pass from steam to exhaust port to regulate the amount of steam cushion at ends of stroke are recommended for 750 and 1000 gallon pumps; a gauge should be provided which will show at all times the length of stroke that the pump is making; water-pressure gauge with $\frac{1}{4}$-inch lever cock should be connected close to the air chamber; a relief valve of Ashton, Crosby or similar pattern and of size sufficient to discharge the full throw of the pump working at $\frac{2}{3}$ speed should be furnished and set to 100 pounds pressure; this valve should have a hand wheel conspicuously marked showing the direction to ; relief valve should discharge downward into a vertical pipe, thence into a funnel; $\frac{3}{8}$-inch brass drip cocks with lever handles should be on both ends of the steam and water cylinders; a $\frac{1}{4}$-inch lever air-cock should be on the cover over the water cylinders; each pump should be fitted with brass priming pipe, starting with a 2×1×1 inch brass tee close to the pump beneath the delivery flange and leading to four $\frac{3}{4}$-inch valves, one opening to each of the four plunger chambers; a priming tank should be provided with bottom at least 5 feet above the pump, and having a capacity half that of the pump in gallons per minute, unless water flows to the pump under pressure; priming tank must be used only for that purpose; each pump is to be fitted for hose connections as per number of streams to be served; capacity of cylinders, sizes of piping, air and suction chambers and relief valves should be as per Table VII.

A special acceptance test is demanded as follows: The pump must run smoothly and without slamming at its full rated speed, maintaining a water pressure of 100 pounds per square inch when furnished with steam at a pressure of 45 pounds for the 500-gallon pump, 50 pounds for the 750-gallon pump, 55 pounds for the 1000-gallon pump. The water to be discharged through $1\frac{1}{8}$-inch nozzles on hose lines 150 feet long; the hose must lie quiet, showing uniform delivery; with all water outlets closed and steam supplied to give 80 pounds water pressure, leakage must not allow

TABLE VII.

Dimensions and Capacities of Fire Pumps.

No. of 1⅛-inch Streams.	Capacity, Gals. per min.	Ratio of Piston areas.	Boiler H. P. needed.	Steam press. needed at pump. Lbs. per sq. in.	Nearest commercial Size. Inches.		
					Diam. steam cylinder.	Diam. water cylinder.	Stroke.
One. (Too small except for auxiliary.)	320	4 to 1	....	40	10	5	10
					12	6	10
					10	5	12
					12	6	12
Two. (For small mills.)	500	4 to 1	100	40	16	8	10
					14	7	12
Three. (For general use.)	750	3 to 1	115	48	16	9¼	10
					16	9	12
Four. (For large factories.)	1,000	3 to 1	150	44	18½	10½	10
					18	10	12

For over 1,000 gallons per minute, two pumps should be used.

Capacity, Gals. per minute.	Diameter of pipes in inches.				Capacity, gallons.		Diameter Relief Valve, Inches
	Suction.	Discharge.	Steam.	Exhaust.	Air chamber.	Suct. cham.	
320	6	5	2½	3	10	8	2½
500	8	6	3	4	17	13	3
750	10	7	3½	4	25	18	3½
1,000	12	8	4	5	30	24	4

the pump to make more than one double stroke per minute; with water outlets nearly closed and pump running slowly it must carry water pressure of 240 pounds per square inch and all joints remain practically tight; with relief valve set at 100 pounds and all other outlets closed it must discharge full delivery at 50 double strokes per minute with the water pressure rising to not over 125 pounds.

These specifications call for a first-class design and construction, but such are necessary if a fire pump is to serve its purpose of a protection in case of emergency.

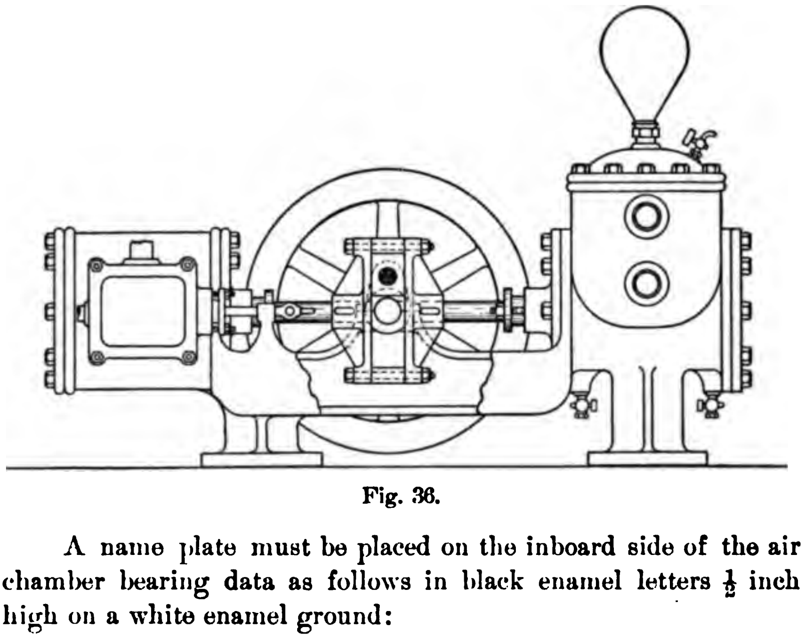


Fig. 36.

A name plate must be placed on the inboard side of the air chamber bearing data as follows in black enamel letters $\frac{1}{2}$ inch high on a white enamel ground:

Diameter of cylinders and stroke 16×9×12. Capacity gallons per minute 750 or three $1\frac{1}{8}$-inch smooth nozzle streams. Full speed, revolutions or double strokes. "For Fire purposes never let steam get below 50 pounds, nights or Sundays."

TYPES.

In classifying pumps by types, two methods of division naturally suggest themselves; the first according to the arrangement of the water end, the second according to the means of driving employed. The difference between single-acting and double-acting pumps has already been noted; the single, duplex or triplex arrangement, depends on whether one, two or three cylinders are assembled into a single machine, drawing water from the same suction inlet and discharging it into the same outlet.

The single pump is much used for small sizes or where constancy of flow is of minor importance. It is, of course, the cheapest arrangement and gives satisfactory results if the pump is of ample size for the work. A difficulty with this type of pump is the provision of a means of operating the steam valve to reverse the motion of the piston at the end of the stroke. The pistons in steam and water cylinders must be stopped gradually to avoid pounding, and this leaves no force available just at the end of the stroke when it is needed to move the steam valve so as to reverse the motion.

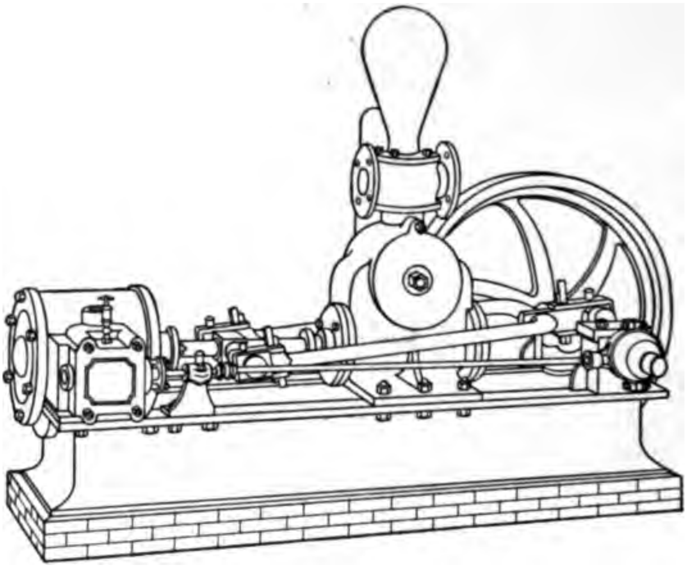


Fig. 37.

The difficulty has been overcome in two ways; first by the introduction of a shaft and fly wheel, driven by a crank and a yoke in the rod between the steam and water cylinders as seen in Fig. 36. The inertia of the fly wheel then furnishes the force needed to move the valve at the instant of reversal, generally by means of an eccentric on the shaft. This form is often used for fire-engines, two or three sets of cylinders sometimes being connected to one shaft, in which case the pump becomes of duplex or triplex form. For stationary pumps, the fly wheel and shaft are more commonly placed beyond the cylinders at one end of the frame, and the shaft is driven by a crank and connecting-rod mechanism from a crosshead attached to the piston rod as seen in Fig. 37. The fly wheel also makes it possible to use steam expansively. The second method of effecting reversal is by the use of an auxiliary valve and steam-driven main valve. This is the system generally found on small, single-cylinder, direct-acting pumps for boiler feeding, tank filling and similar uses. The details of the devices used vary greatly with different makes; these will be taken up later.

The single pump is compact, cheap and convenient, but the flow of water is by a series of impulses rather than in a steady stream, so that, if the pump is forced, it slams badly and produces water hammer, an evil but partially remedied by the use of discharge and suction air chambers.

Duplex pump. To avoid this, and at the same time to simplify the moving of the steam valve, the late Henry R. Worthington devised the duplex form, in which two direct-acting pumps are mounted side by side, the water ends and the steam ends working in parallel between inlet and exhaust pipes as seen in Fig. 38. The steam valve for cylinder A is moved by a bell-crank lever driven from the rod of cylinder B as it nears the end of its stroke; so that, when the piston of B is about to come to rest, that of A is set in motion. While the piston of A makes its stroke, that of B is at rest until that of A, near the end of its stroke, moves the steam valve of cylinder B by means of a second bell-crank lever, and the piston of B is once more set in motion. Thus the pistons move alternately, but one or the other is always in motion and the flow of water is made practically continuous. By this arrangement the auxiliary steam valve is made unnecessary and a simple D valve, driven by a valve rod running through a stuffing box, is used.

The triplex pump having three cylinders delivering to the same outlet is generally used for power pumps; the pistons or plungers are driven from a shaft by three cranks or eccentrics, set at 120 degrees to each other so that the turning effort required on the shaft may be as uniform as possible and the flow of water steady. A style often used is single-acting with trunk plungers, that is, the connecting rod which drives the plunger is fastened to a pin inside the hollow body of the plunger as seen in Fig. 39. This gives a compact form and one not likely to get out of order, but the trunk arrangement is inconvenient in case of any wear on the pin inside the plunger, and the side thrust of the connecting rod creates a certain tendency to wear the plunger packing so that it will not remain tight. On the whole it is better, though more expensive, to have a regular crosshead and ways to receive the thrust of the connecting-rod as in Fig. 42. The cylinders in this style of pump are usually vertical and the crank shaft is driven through a pair of reducing gears from a second shaft which is, in turn, driven by a pulley and belt or an electric motor.

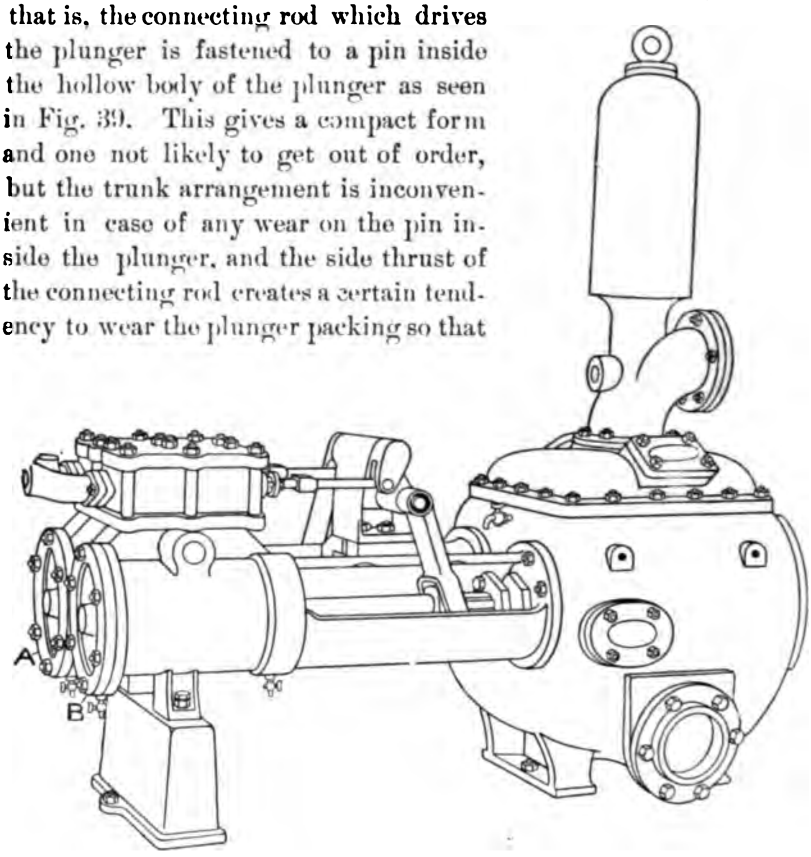


Fig. 38.

Methods of Driving. With respect to the method of driving, the most common type of pump is the direct-acting, steam-driven, with steam piston and water piston or plunger on opposite ends of the same rod. For small sizes, the steam cylinder works without expansion of steam, the piston being driven by full boiler pressure throughout the stroke. In fact it is impossible to avoid this feature of full-stroke admission, since the pressure in the water end is constant throughout the stroke, unless some means, such as a fly wheel or accumulator, be provided, a complication which is undesirable with small powers. The simplest way to make any use of the expansive force of the steam is by compounding; that is, letting the steam exhaust from the small, high-pressure cylinder, into which it is first admitted, to a larger low-pressure cylinder, placed in tandem, with the first one. See Fig. 40. This arrangement gives a pressure on the low-pressure piston, which gradually decreases from the beginning to the end of the stroke while the pressure on the high-pressure piston is constant, so that whatever useful work is gained from expansion is in the low-pressure cylinder. This is, however, found to be sufficient to pay for the extra cost if the service is continuous, in sizes having a water cylinder over 8 × 12 inches. The compound pump is nearly always duplex, though a few manufacturers offer a single tandem-compound style. Since the steam pistons must move together, the steam valves must move together, and a single motion serves to operate the valves for both high and low-pressure cylinders.

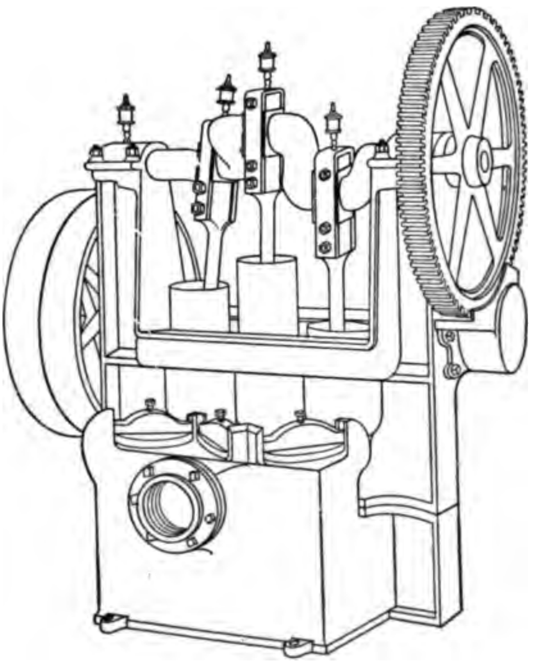


Fig. 39.

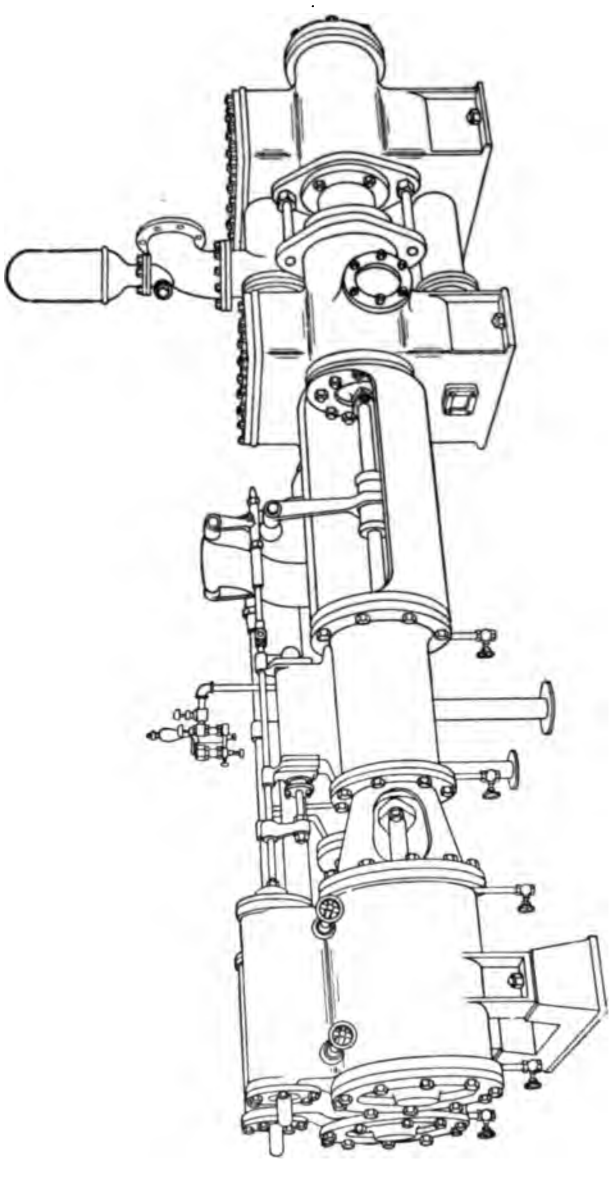


Fig. 40.

The simple steam-driven pump requires from 60 to 120 pounds of steam per horse-power, per hour; the gain by compounding is about 30 per cent per 100 pounds increase in boiler pressure, so that the steam consumption will be 40 to 95 pounds per horsepower hour.

The volume of the low-pressure cylinder is made from 2 to 4 times that of the high-pressure, depending on the initial pressure to be used.

The large steam consumption of direct-acting pumps of the single-cylinder type has led to the adoption, in many large stations, of power-driven pumps of various kinds. It is probably true that the cost for steam is less by this method when the power is developed by large engines, even after the losses in transmission are accounted for, because the efficiency of the engine is so much greater than that of a small pump. But, for small plants, the convenience of having the pump located near its work and of being able readily to control the speed has overbalanced the consideration of saving.

As previously mentioned, nearly all power pumps are geared, the power being applied to a driving shaft as seen in Fig. 39. The belted type is driven from a countershaft and provided with fast and loose pulleys used for starting and stopping, but there is usually no means of speed regulation. This, together with the expense of belting, the room needed and the fact that the convenient location for a pump is likely to be such as to make a belt a nuisance have prevented a general use of this type, and with the general introduction of electric power into all plants, the motor-driven pump is superseding it.

The motor-driven pump is of the same general form as the belted, but has an electric motor mounted on the driving shaft in place of the pulley, or has a double-reduction gearing as in Fig. 41. The high speed at which motors run make this double reduction necessary except in the case of large pumps. The only alternatives are the use of a large, slow-speed motor or a belted motor, either of which would be cumbersome and expensive. As to efficiency, probably there is not much difference between the belted and the motor-driven types. The electric method of transmitting power from the engine to the pump will be more economical than belting, but the transformation in the motor and the loss in the extra set of gears will offset this.

The speed of the motor can, however, be controlled by a starting box, or rheostat in the field circuit, hence the motor-driven has a considerable advantage over the belted type.

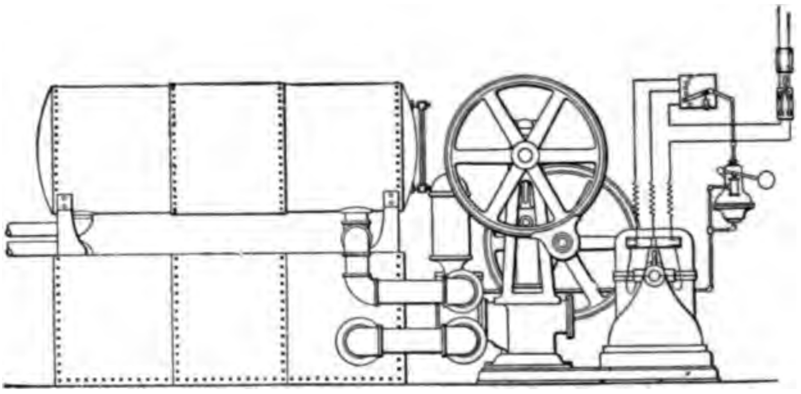


Fig. 41.

As compared with the direct-acting type the economy would be about like this:

Direct-acting—steam consumption, average, 90 pounds per hour per H. P.

Belt-driven—steam consumption of engine, per B. H. P. hour, average 35 pounds; at an efficiency of transmission for belting of 70 per cent and for gearing of 85 per cent, this would require about 59 pounds of steam per hour per H. P. delivered to the pump and at an efficiency of 75 per cent for the pump this would give about 78 pounds of steam per hour per H. P. of effective work.

Motor-driven—steam consumption as before, 35 pounds; efficiency of dynamo 93 per cent, of transmission 90 per cent, of motor 93 per cent, of gearing 72 per cent, of pump 75 per cent, gives a steam consumption per effective H. P. of 83 pounds per hour.

Of course with large units the efficiencies may be better, but the relation would be about the same. The greater convenience of the direct-acting pump as to size and means of control, and the ability to start it when the engine is not running have weighed in its favor in the majority of cases.

For some few places a gas or oil engine has been used for pump driving. In this type a clutch must be introduced between the engine and the pump, Fig. 42, as the engine will not start under load. The engine must first be started, then the pump thrown on empty and finally the valves operated so that the pump will begin to work. There is no means of varying the speed, but a regulator is sometimes introduced which throws out the clutch when the water reaches a certain height in the tank or reservoir to be filled. This type is used only for such service as water supply for a house or reservoir system, and would hardly be desirable elsewhere.

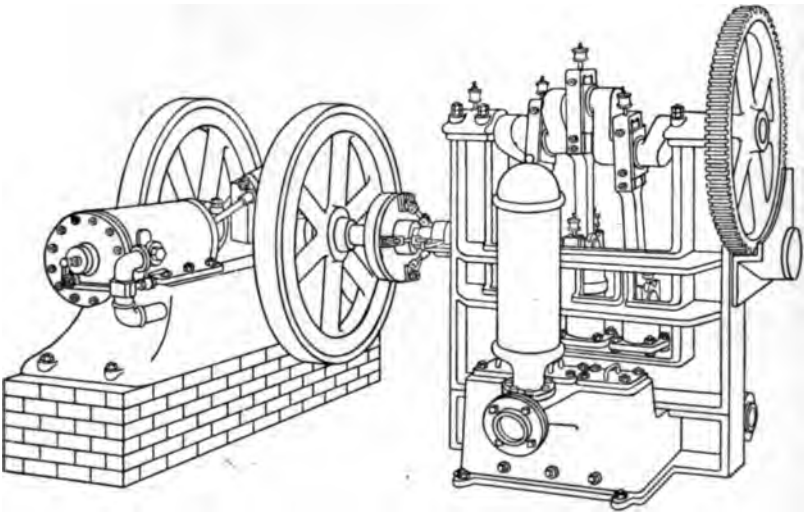


Fig. 42.

To economize in floor space, the vertical marine type of pump is used. This is generally duplex, but occasionally single, and except for the vertical arrangement is identical with the horizontal type.

Another special type is the **combined-condenser pump**, Fig. 43, in which the steam cylinder is placed in the center and drives on one end of the piston rod a vacuum pump for drawing the condensed steam and air from the condenser, and on the other end a pump for forcing the cooling water through the condenser tubes. The steam cylinder is the same as for any single pump except that there is a stuffing box at each end; the water end is the same as for any pump; but the air-pump end has composition disc valves with an area of opening larger than that for a water cylinder of the same size, and the springs which close the valves are set at a less tension than for water.

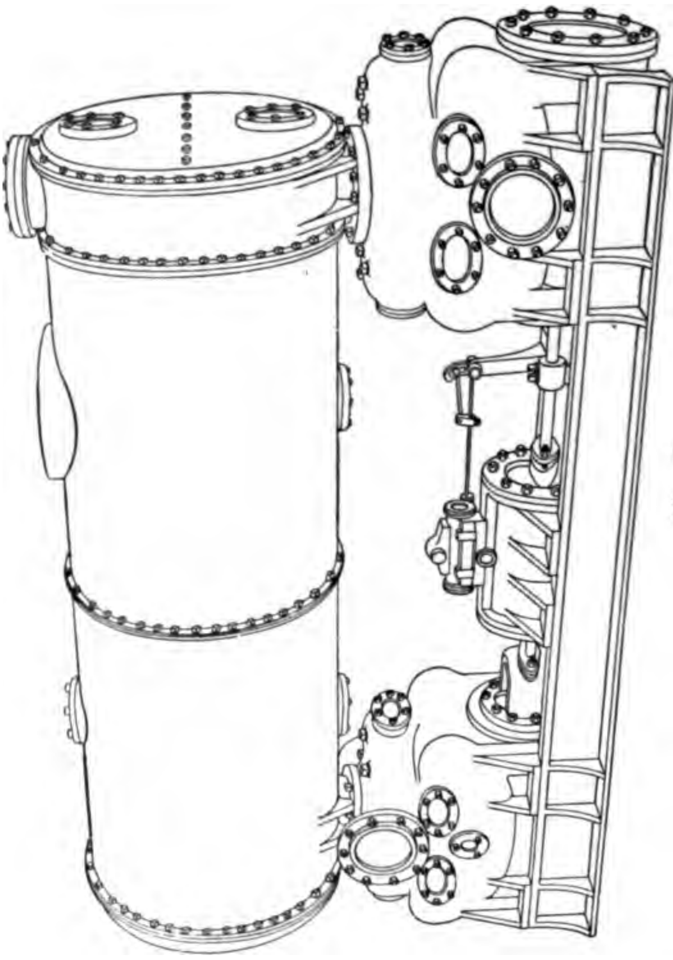


Fig. 43.

Air pumps of special forms for condensers are often used combined with the condensers; they are driven by a separate engine or by a bell-crank lever from the crosshead of the main engine. The cylinders are often vertical and single-acting on the lifting principle with valves in the top of the bucket. A unique and in some ways commendable style is that of Fig. 44 which avoids inlet valves and valves in the bucket, yet removes both air and the water of condensation quickly and effectively. Condensed steam and air flow into the lower recess A through the passage B from the condenser; as the piston descends, it forces the water from A so that it shoots up in the direction indicated by the dotted lines through the ports *p p* into the cylinder C. The piston rising, closes ports *p p* and catches the water and air in the cylinder forcing them out through the valves *v* in the top into the discharge chamber D, whence the mixture escapes through the exhaust passage K to the hot well, or wherever may be desired.

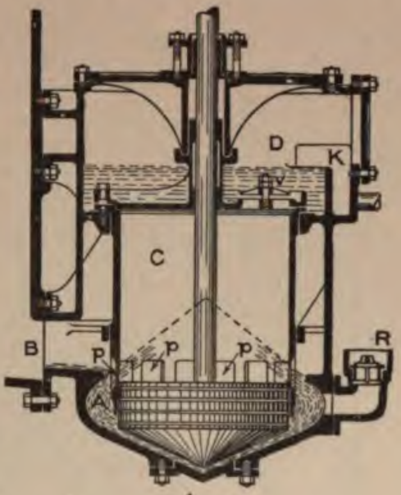


Fig. 44.

For certain uses, such as keeping up the pressure on a hydraulic elevator system, draining a pit or maintaining the water level in a tank, it is essential to have an automatic method of control which shall start and stop the pump as may be needed. For direct-driven steam pumps this is accomplished by control of a damper valve or a quick-acting gate placed in the steam pipe and for the motor-driven pump by a switch on the starting resistance box. In the one case, a float is moved with the water level, in the other a diaphragm worked by the tank pressures actuates a series of levers as seen in Fig. 41 so as to work the steam valve or switch as the case may be.

For high pressures and high speeds what is known as the Riedler System of mechanically operated valves (Fig. 45) is found especially desirable. The valve is of the poppet type, made so large that one valve answers for each end of a cylinder and is opened and closed by a rocking arm N, turned by a link and driven from a wrist-plate much as in a Corliss-engine valve motion. The mechanical driving permits a high lift, with rapid opening and closing at the end of the stroke, thus decreasing the slip and shock. The high lift, 1 to 2 inches, and large water passages decrease the friction while the mechanical operation of the valves also allows of the high piston speed necessary to secure economy in steam consumption.

Referring to Fig. 45, the valve body P has on its lower face a leather seal S secured by a plate O. The sleeve D works on the spindle B, raised by a pin in the arms K which passes under the collar H and is lowered by the pressure of the blocks J on the cushion plate G. F is a rubber buffer to take the shock in case an obstruction gets into the valve. The arms K are mounted on and turned by a spindle which passes through the bushing C and is rotated by the crank L and crank pin N. One valve is used for inlet and one for outlet on each cylinder, as seen in the right-hand plunger of Fig. 46; for the left-hand end, the outlet valve of the larger plunger acts as an inlet and the clack valve between passages

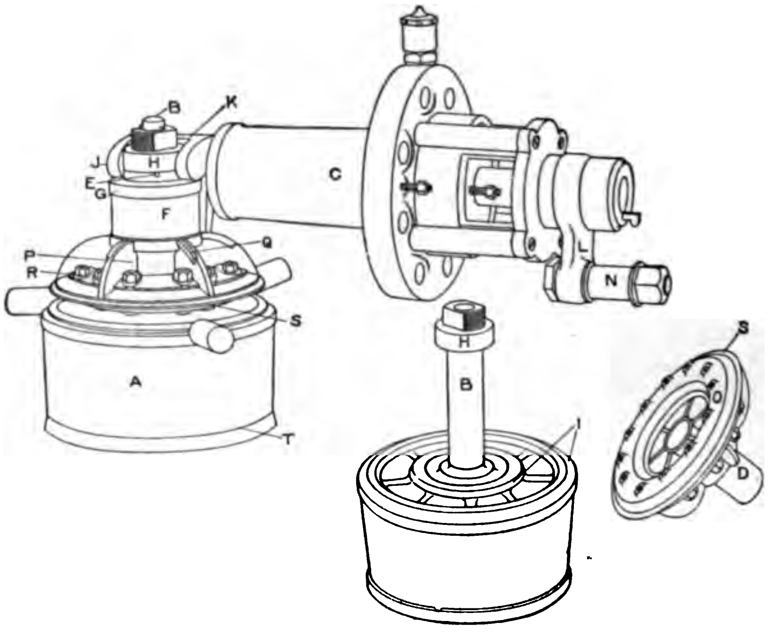


Fig. 45.

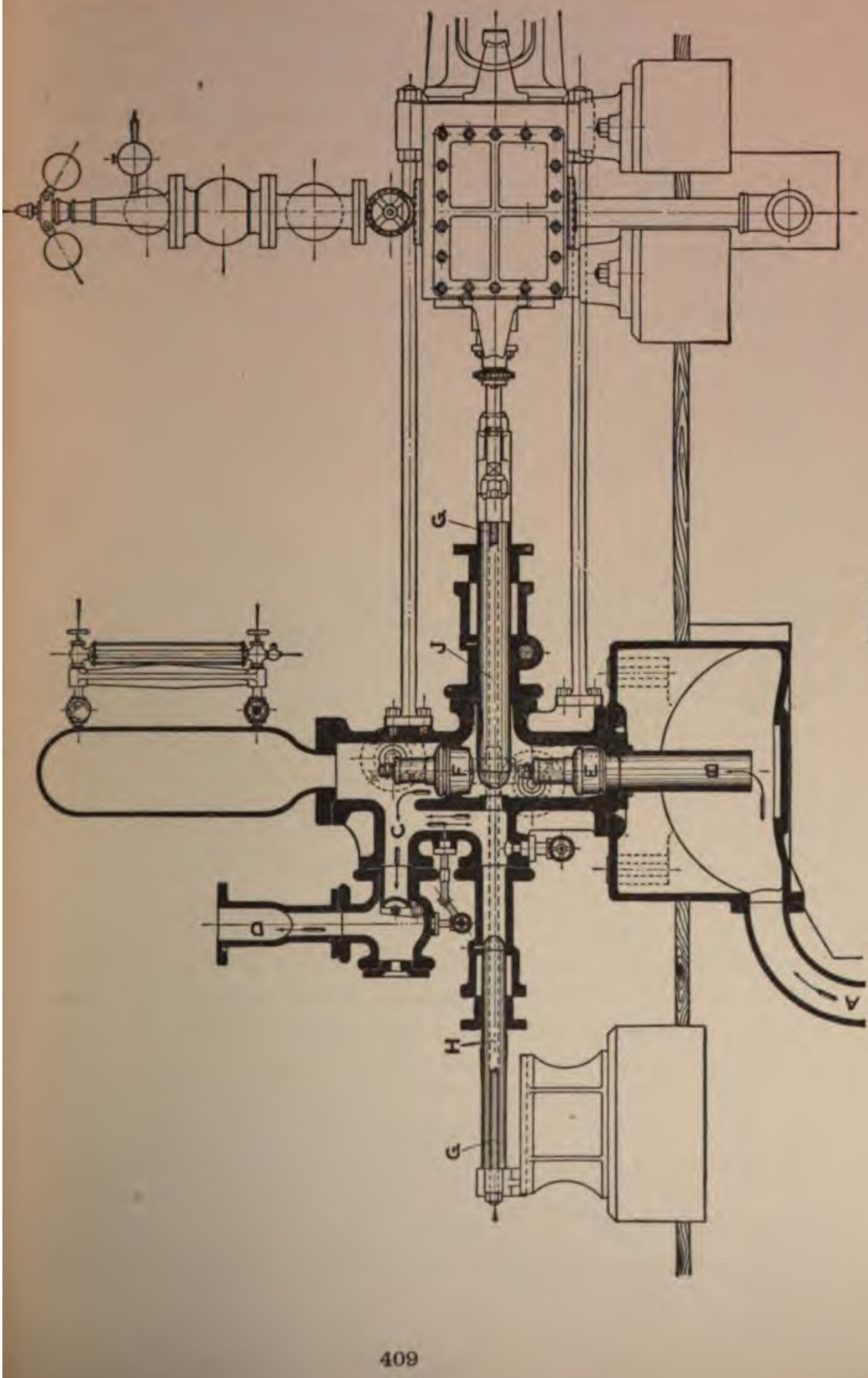


Fig. 46.

C and D acts as an outlet valve. The differential type of pump here shown is used for high pressures and to give a continuous flow with few valves; the cross-section of plunger H, (Fig. 46), is half that of J, hence, on the stroke towards the left, half the water discharged by J is thrown into the small plunger chamber and half into the passage D; on the stroke towards the right, the half which entered the small plunger chamber is driven into chamber D and the large plunger draws its full quantity through the suction pipe B. The large passages and valves, the ample discharge and suction air-chambers, together with the positive opening of the valves, combine to make this pump very efficient and quiet in running. However, it requires a large space in proportion to its capacity while its complexity makes it expensive, so that it is available only for large sizes and in places where the space occupied is not of special importance.

STEAM VALVES.

The simplest form of valve is that used with a fly-wheel pump and which is moved by an eccentric as seen in Fig. 37; the detail is shown in Fig. 47 and the action as follows:

With the valve *v* in the position shown, steam is flowing through the port *a'* into the right-hand end of the cylinder and forcing the piston towards the left; at the same time, any steam which may be in the left-hand end of the cylinder is driven out through the port *a* into the exhaust passage *b* and thence to the exhaust pipe. If the shaft M be turning as indicated by the arrow, the eccentric *e* which is keyed to it, will also turn, and sliding in the eccentric strap S will draw it towards the right, and with it the valve. When the eccentric has made a fourth of a revolution it will be vertically above the shaft, and will have drawn the valve over so that it covers both ports, while, at the same time the piston will have moved so that it will stand at its extreme left-hand position. As the motion continues, the left-hand port *a*, will be opened to steam and the port *a'* to exhaust, causing the piston to reverse and move towards the right, which will continue until the eccentric has moved the valve to its extreme right-hand position and back to cover both ports. The eccentric standing directly below the shaft, the piston will again reverse and start towards the left, and the cycle be repeated.

This style of valve is called the D valve, and is much used for pumps and for the smaller reciprocating steam engines. For the ordinary pump the valve is made so that when in mid position it just covers the ports, and steam will enter one or the other end of the cylinder, if the valve is moved from that position. Steam will then be admitted full stroke and work without expansion in the cylinder. If it is desired to utilize some part of the expansive force of the steam, "lap" must be added to the valve as shown at *a*, Fig. 48, so that the port may be closed before the piston reaches the end of the stroke; then the eccentric must be turned forward on the shaft in the direction of its motion in order that the valve may open by the time the piston is ready to reverse, and then "inside lap," *b*, must be adjusted so that the exhaust port will neither open too soon, thus wasting the expansive energy of the steam, nor close too early, thus causing too great a compression of the steam caught between the piston and the end of the cylinder.

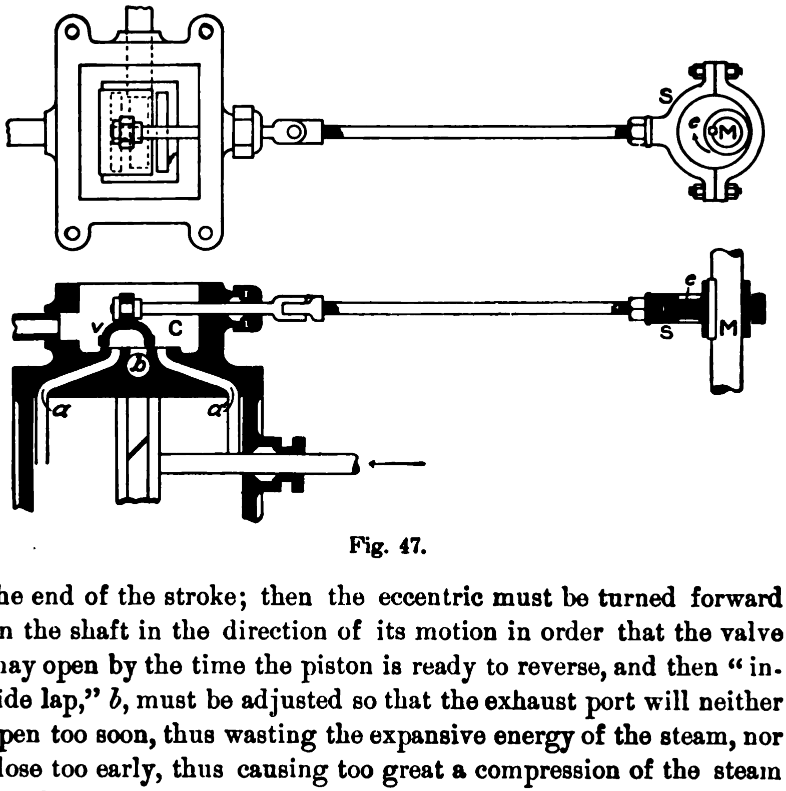


Fig. 47.

The construction is the same as for a simple reciprocating engine, which indeed it is, with the addition of a pump cylinder and piston attached to the end of the piston rod.

Another form of valve common in pumps is the B type, Fig. 49. The action is the same as for the D type, except that steam flows into the cylinder through the cup-shaped cavity in the valve instead of past the end, and the motion of the valve relative to that of the piston is the opposite of that for the D valve. The B type is adapted for use with the steam-driven valve to be described, but is not suited to be driven by an eccentric. The steam-driven valve is used on the great majority of small single pumps on account of the compactness, light weight and low cost and in spite of the poor steam economy. In a few of the first named pumps, for instance, the early Worthington, single type, the main steam valve was moved by tappets on the valve rod which were struck by an arm fastened to the piston rod. This was not certain in its working and has been displaced by the main valve moved by a small piston working in an auxiliary cylinder. Steam is admitted to this cylinder by an auxiliary valve moved by a tappet or lever mechanism worked from the main piston rod.

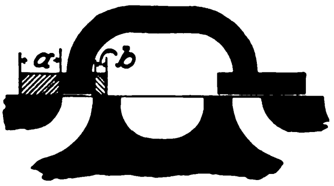


Fig. 48.

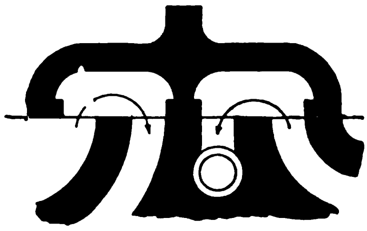


Fig. 49.

The designs of different makers vary more in this detail than in any other, and we shall now discuss a few typical examples at some length.

The first to be developed was the Knowles, Fig. 50. The chest piston A is moved by steam admitted through ports *m* and *z* between the end of the chest piston and its cylinder, and carries with it the main steam valve B, which opens and closes the ports to the main steam cylinder. The ports *x y z* and *x′ y′ z′*, of the small detail view, are made to register with the ports *m n* and *m′ n′* by the turning of the chest piston by the tappet C driven by the rocker-bar R and the roller E. As the main piston reaches its left-hand position, the roll E will lift the left-hand end of the rocker bar and place the ports so that steam is admitted to the right of the chest piston and exhausted from the left; the main valve will then be carried to the position shown in Fig. 50 and steam be admitted to the left-hand end of the main steam cylinder in order to drive the main piston towards the right. At the other end of the stroke the operation will be reversed. The arm F will not strike tappets C or D unless the steam fails to move the main valve, in which case the piston A would be driven by pressure on the tappets, but with more or less slamming depending on the speed.

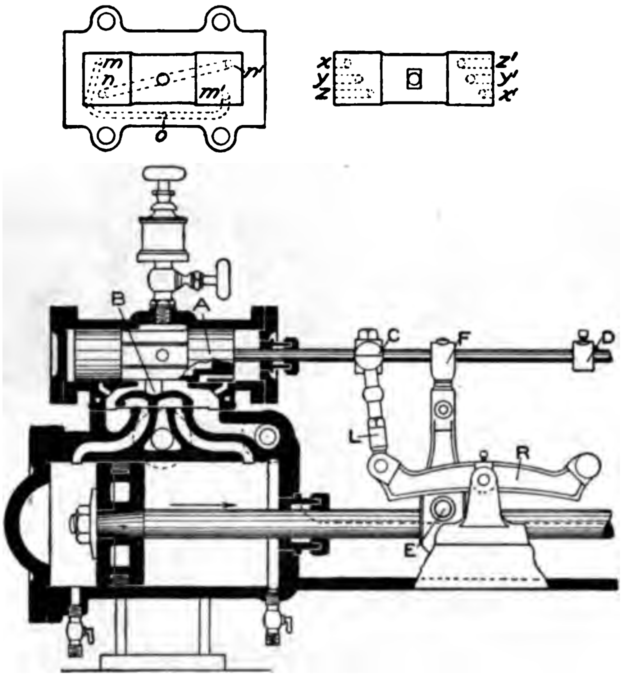


Fig. 50.

The third set of ports in the chest piston and its seat are to form a connection between the two ends of the auxiliary cylinder after the chest piston has moved a certain distance in order to prevent its striking the end of the chest. The length of stroke can be changed by altering the height of the roller E, and unevenness of stroke at the ends can be remedied by changing the length of the link L.

An entirely different style of valve is that of the Cameron pump, Fig. 51. F is the valve-piston which drives the valve G, by means of a projection which sticks up through the neck of the piston. The ends of the valve piston are hollow as shown in the cross-section of the right-hand end, and a small hole P, at each end admits steam at full pressure to the ends of the chest cylinder. If the main piston C is moving to the left (as it would be with the valve G in the position shown), when it reaches the end of the stroke, it will strike the reversing valve I′ and force it open, thus allowing the steam at the left of the valve piston to flow into the exhaust port through the passage E′. The steam at the right-hand end of the valve piston will expand, forcing the piston F to the left and carrying valve G with it, thus opening the right-hand end of the main cylinder A to the exhaust and the left-hand end to live steam, which will reverse the motion of the piston C. As the valve piston moves to the left, it will cover and close the port E′ hence will be brought to rest without shock by the cushioning of the enclosed steam. As soon as the piston C leaves it, the reversing valve I′ will be closed by the pressure in the passage K′ which is filled with live steam. At the other end of the stroke, the same series of operations follows by the action of the reversing valve I.

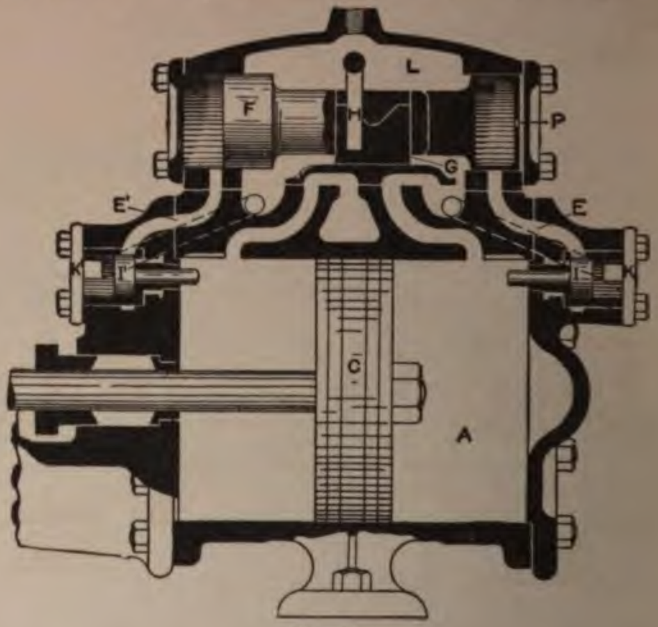


Fig. 51.

The valves require no adjustment and are easily brought to a new seat when they become worn, by removing the bonnets. If piston F becomes worn after long service, the cylinder may be re-bored and bushed or the holes P may be drilled a little larger, which will give greater pressure in the end of the chest cylinder and keep the pump working steadily for a long time even with the piston F considerably worn. H is a starting lever, worked by a handle outside, for use in case the pump should stop with the valve G covering both admission ports.

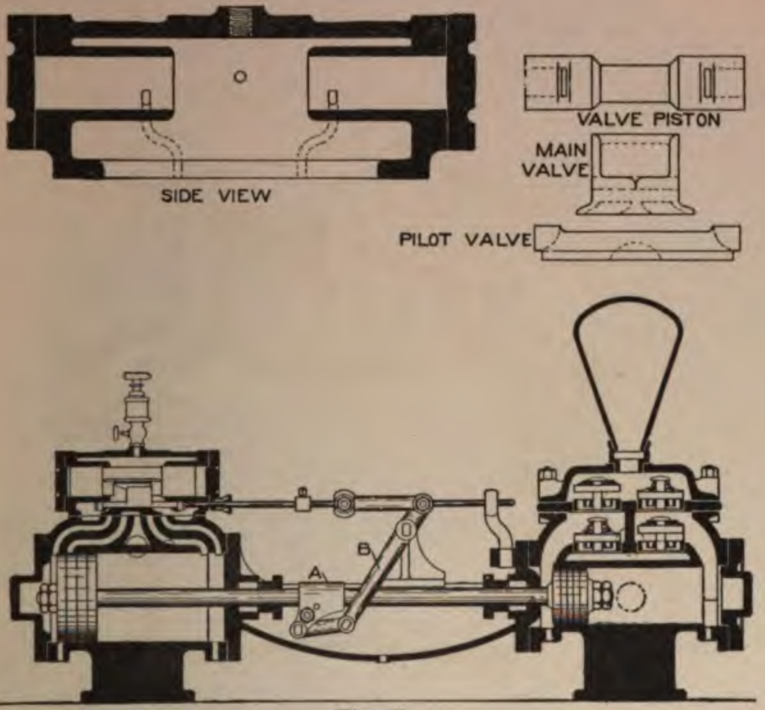


Fig. 52.

A third style of valve is shown in Fig. 52, that of the Deane of Holyoke. In this the auxiliary valve is in the form of a yoke surrounding the main valve; the working-valve seat and ports for the auxiliary are at one side of the main-valve seat, and the ports supply steam to or exhaust it from the ends of the valve-piston chamber through openings in the end of the piston. The auxiliary valve is moved by a valve rod actuated by tappets and a series of levers from the main piston rod. If the valve piston fails to move the main valve, the auxiliary valve, acting as a yoke, will finally drive the main valve over, by positive action.

A somewhat similar device is used on the Dean Bros'. pump, Fig. 53. There is, however, no period of rest of the auxiliary valve, the motion being similar to that given by an eccentric, and there is no provision for moving the main valve other than by the valve piston, because the positive driving of the auxiliary valve makes this unnecessary. The auxiliary valve F works on a seat G on the side of the valve-piston cylinder, being driven by the rod A and the rocker arm R from the main piston rod P. The length of its stroke can be changed by moving the pin B in the slot of the rocker arm, and the stroke of the main piston will thus be changed. The main valve is of the D form with a projection from the top which is engaged by the valve piston; the ports enter the cylinder, as in practically all direct-driven steam

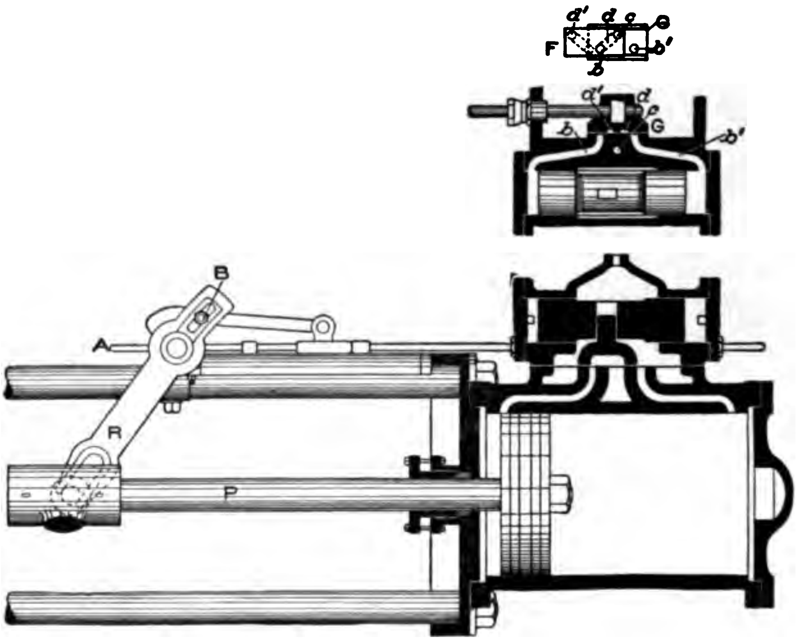


Fig. 53.

pumps, at some distance from the end; thus steam will be caught to form a cushion for the piston at the end of the stroke.

The auxiliary valve, Fig. 53, is made very short and is so arranged that its ports are open only when the main piston is near the end of its stroke. Ports *b b'* are for admission of live steam and port *c* is for exhaust. All three ports are covered by the valve except when near the end of its travel; then the groove *d* in the face of the valve connects ports *b* and *c* and allows the steam to exhaust from the left-hand end of the valve piston while port *b'* is uncovered and live steam is admitted to the right-hand end; or, at the opposite end of the stroke, groove *d'* connects *b'* and *c*, and *b* is uncovered. This construction prevents waste of steam if the valve piston becomes worn in its cylinder, since live steam is conducted to that cylinder only during the moment of moving the piston. The stroke of the pump can be easily regulated and the action is noiseless.

A valve with a peculiar cut-off action is used on the Blake pump. In this, as it stands in Fig. 54, steam is entering the head end of the cylinder through the ports E and H, and is exhausting from the crank end through ports H', E', K and M. As the main piston A nears the crank end of the stroke, the valve C is moved to the left by a system of levers similar to those on the Deane pump, which strike tappets on the rod P. When this happens the lug S on the valve C covers the auxiliary steam port N, and S' uncovers the auxiliary steam port N' (see plan view), while the auxiliary exhaust port Z is disconnected from X' and connected to X, thus allowing steam to exhaust from the piston chamber at B' and flow into that at B. The main valve D will be carried to the right by the supplemental piston and will connect port E to K, leaving E' uncovered for the entrance of live steam, and the main piston will be forced towards the head end. It is not necessary to provide for positive mechanical driving of the main valve, as live steam can always enter one end or the other of both main and supplemental cylinders. The supplemental piston is fitted with rings so that it will take up its own wear, and prevent leakage into the exhaust, while the motion is such that the main valve has a slight lead on the main piston, thus admitting live steam to cushion the latter at the end of its stroke and prevent slamming. Also, in case the main valve sticks, the valve C moves far enough to admit sufficient steam past the end of the main valve for the cushioning effect. The supplemental piston cushions on the steam caught as it passes by the end of the port X or X′.

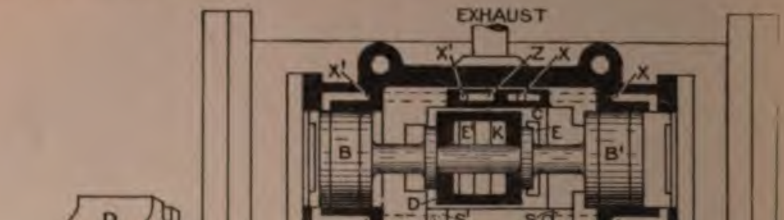


Fig. 54.

The Davidson pump, Fig. 55, has but one valve, operated by an auxiliary piston. The admission of steam to the ends of this piston is accomplished by the oscillating motion of the main valve itself. This motion is caused by a pin turned by a cam and oscillating lever driven from the pump rod. In the position shown, steam is being admitted to the crank end and exhausted from the head end; consequently the piston is moving towards the right. As it nears the end of the stroke, the cam C will rotate the pin D and place valve A in position to connect the port E′ with the exhaust chamber while opening E to live steam as seen

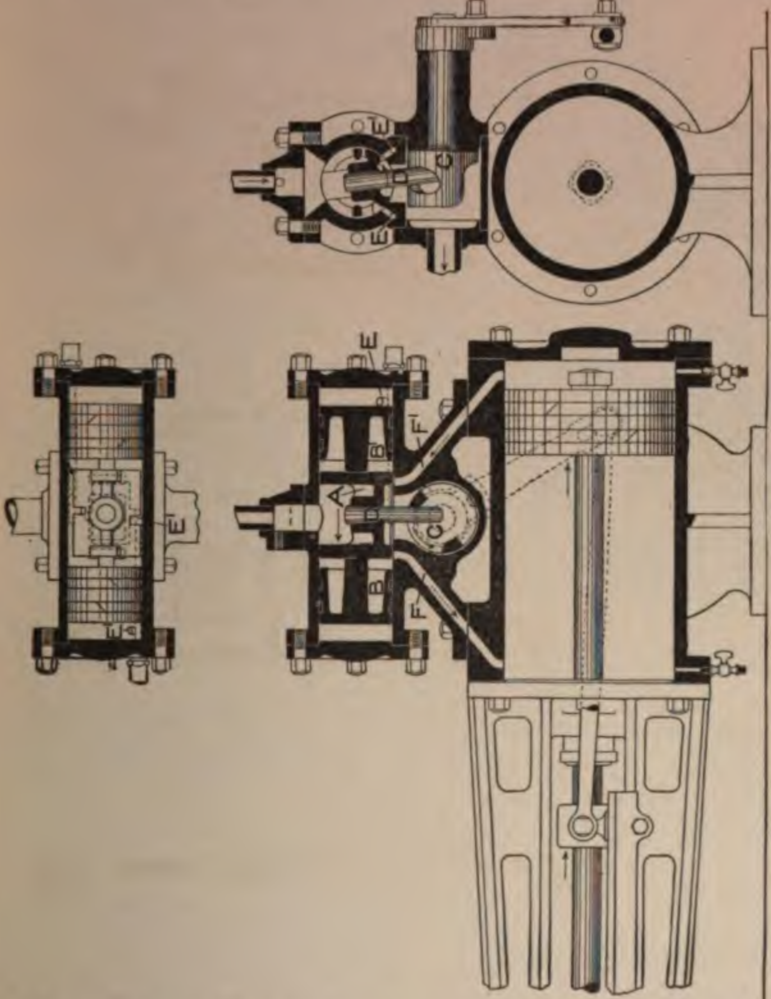


Fig. 55.

in the end view. The pin D will then be driven towards the left, carrying with it the valve A. Ports E′ and F will be closed so that the main piston will be cushioned on the steam remaining in the cylinder.

The movement of valve A to this central position opens E′ to exhaust and E to live steam, and the piston B B′, carrying with it valve A, is forced to the left, opening port F to exhaust and F′ to live steam, and allowing the main piston to move towards the left When valve A is in a position to cover both ports F and F′, either E is open to steam and E′ to exhaust or vice versa, consequently the pump is always ready to start as soon as steam is turned on.

Various other forms of steam end have been used by different makers, but they work on practically the same principles as those described, being different only in details.

The duplex pump, as already explained, has two sets of cylinders side by side. The steam valve on one side is moved by means of a valve rod and lever connected to the piston rod on the other side, so that one side starts when the other has reached about three-quarters stroke. The steam valves are usually of the D form, having separate ports for admission and exhaust at each end as seen in Fig. 56. In this figure, valve B is moved by rod C and bell-crank lever D, the hidden end of which is driven from the farther piston rod by a device like H, while the farther valve is driven by the rocker-arm lever G F E. The double ports are used so that the piston may run over the exhaust port and close it before reaching the end of the stroke, thus getting a steam cushion, and yet live steam may have a chance to enter behind the piston even if it stops quite at the end of its possible motion. In large sizes (particularly in fire pumps) a cushion valve is placed

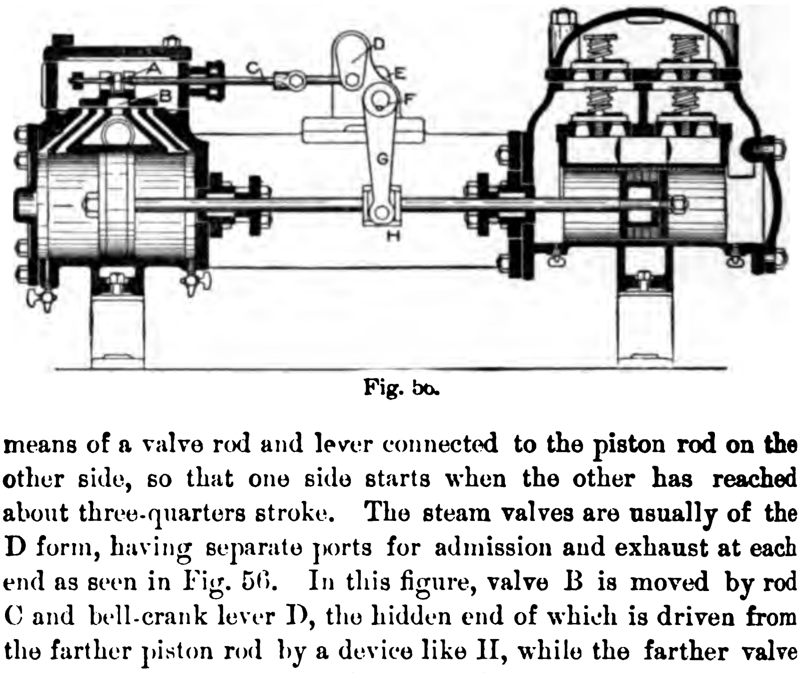


Fig. 56.

in a passage connecting the steam and exhaust ports, so that the amount of by-pass opening between them may be adjusted, thereby regulating the cushioning to any desired amount.

In order to secure the rest period at the end of each stroke, which is needed for quiet running and small slip, it is usual to introduce a lost-motion device in the valve-driving mechanism. In Fig. 56 this is the nut A, which has a thickness less than the space between the lugs on the valve, thus preventing the valve from being moved until the nut has traveled some distance. In larger sizes it is more common to use a single lug on the valve; the rod passes through this and the lost motion is provided for by adjusting nuts held fast by jam nuts, so that the valve lug will have play between them as seen in Fig. 57. For very large pumps and pumping engines, lost-motion links are usually placed in the end of the valve rod, as seen in Fig. 58; this arrangement has the advantage that the amount of lost motion can be adjusted without removing the steam-chest cover, or even, if desired, while the pump is in motion. It is, of course, somewhat more expensive to construct than the jam nuts shown in Fig. 57, hence is not often used for small pumps.

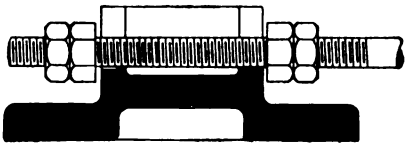


Fig. 57.

The amount of lost motion needed for any style of pump can be determined only by trial, but once fixed will be the same for all pumps of a given style and size. For pumps up to 10-inch stroke, $\frac{1}{8}$ to $\frac{3}{8}$ inch is usually allowed; for larger sizes the requirements call for $\frac{1}{2}$ to 1 inch.

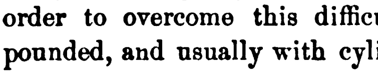


Fig. 58.

Compound Pumps. The simple steam pump must from the nature of its action take steam full stroke, hence has no possibility of using any of the expansive energy in the steam. In order to overcome this difficulty large pumps are often compounded, and usually with cylinders arranged tandem, as in Fig. 59, or with the smaller cylinder outside, as the designer may choose. Steam from the boiler enters the high-pressure steam-chest in the usual way; it then passes to the high-pressure cylinder; from there it exhausts through the side-pipe, seen at the back of the steam-chests in Fig. 59, to the low-pressure steam-chest; thence passes into the low-pressure cylinder and from it to the exhaust pipe. Unless a boiler pressure of more than 80 pounds is used, it is not advantageous to compound a pump run non-condensing, as the saving in steam will not pay for the increased cost. If a condenser is used, compounding may be introduced with profit for pressures as low as 50 pounds; but the added complication of condenser and many cylinders is inadvisable for pumps with low-pressure cylinders smaller than about 18×24 inches.

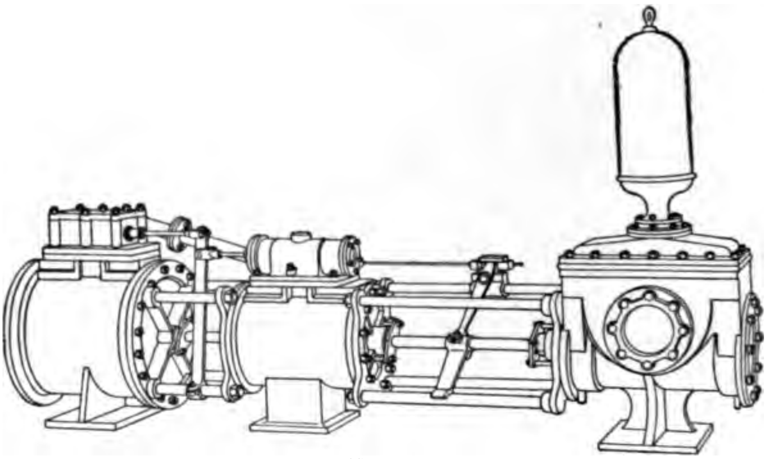


Fig. 59.

Compound pumps are used either single as in Fig. 60 with an auxiliary valve and valve piston, or duplex with the valves driven by the method described for duplex pumps. As the pistons are on the same rod, the valves must move at the same instant, and are usually mechanically connected and driven by the same valve piston or lever, as the case may be. The duplex compound is more often used than the single, and it is considered better practice to use a duplex compound with small cylinders than to use a single compound with larger ones, as the difference in cost will be more than balanced by the steadiness of running

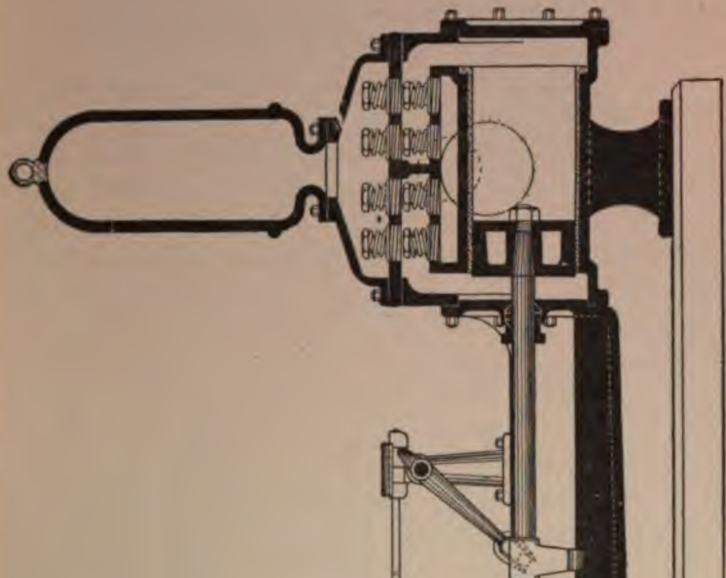


Fig. 60.

The high-pressure cylinder takes steam full stroke so that there is no expansion in it; at the opening of the high-pressure exhaust the pressure drops until it is equalized in the low-pressure steam-chest, side-pipe, high-pressure cylinder, and the clearance space of the low-pressure cylinder, the admission to which opens at the same instant as the exhaust from the high-pressure. On the return stroke of the pump, the steam expands in passing from the high-pressure cylinder to the low-pressure, the action being as indicated in the diagram, Fig. 61, and the nominal ratio of expansion between 2 and 3. In the diagram it is taken as 2.25, vertical distances being laid off to represent pressures and horizontal to represent volumes. The pressure in the passages beteen cylinders is a variable, but is taken as the value at the beginning of the low-pressure stroke. The back pressure in the low-pressure cylinder will be about 2 pounds above that at the outlet of the exhaust pipe, or 17 pounds for a non-condensing pump and 4 pounds for one run condensing.

The action illustrated in Fig. 61 is as follows: Assume that we are dealing with a pump whose high-pressure cylinder A is 16 inches in diameter by 18 inches stroke, and with clearance C 8 per cent of the piston displacement; and whose low-pressure cylinder B is 24 inches in diameter, the stroke being of course the same as for the high-pressure, and the clearance C 8 per cent of the low-pressure piston displacement. The intermediate space between cylinders, side-pipe and low-pressure steam-chest will be, in practice, about 0.35 the piston displacement of the high-pressure cylinder. Assume that the initial pressure is 85 pounds gauge or 100 pounds absolute and the back pressure in the low-pressure cylinder 4 pounds absolute. The line *a b* will represent the action during admission to the head end of the high-pressure cylinder, steam being taken at full pressure for the entire stroke. If we assume the volume of the piston displacement as 1, there will be 1.08 volumes of steam in the high-pressure cylinder and clearance. At the end of the stroke, the exhaust through the side-pipe into the low-pressure cylinder will be opened and the pressure will fall, the amount of the instantaneous drop depending on the pressure in the low-pressure steam-chest at the time the high-pressure exhaust opens. We shall see that this will be about 40 pounds, a value which can be safely assumed as a working basis. When the high-pressure exhaust opens, the admission to the low-pressure cylinder also opens, and the pressure will drop according to Boyle's law, so that it is equalized in the three compartments.

The volume of the low-pressure cylinder will be $1.5^2 \times 1 = 2.25$, and of its clearance $.08 \times 2.25 = 0.18$ volumes. Then the pressure after drop and equalization is found thus:

$$\begin{array}{lcr} 1.08 \times 100 & = & 108.00 \\ .35 \times 40 & = & 14.00 \\ .18 \times 4 & = & .72 \\ \hline 1.61 & & 122.72 \end{array} \qquad \frac{122.72}{1.61} = 76.2$$

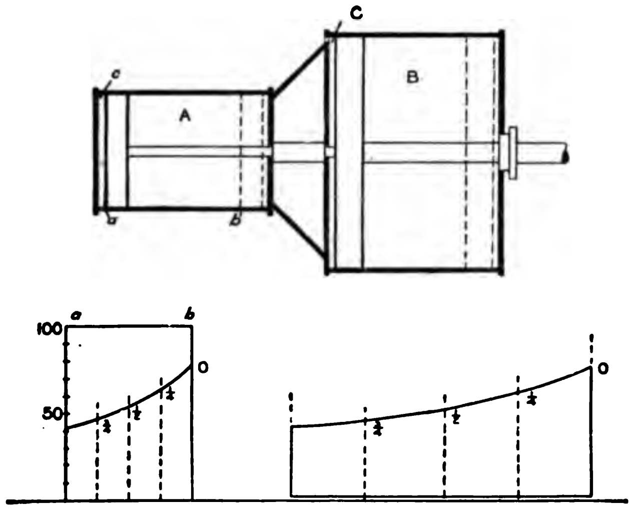


Fig. 61.

The pressure after equalization, 76.2 pounds, is found by multiplying each volume by the pressure existing within it and dividing the sum of the products by the sum of the volumes.

As the pistons return, the volume in the high-pressure cylinder decreases, that in the intermediate passages remains constant, and that in the low-pressure cylinder increases. The result will be an expansion according to the hyperbolic law so that the line showing the back pressure on the high-pressure piston, and that showing forward pressure on the low-pressure piston, will indicate the same pressure at each instant of the stroke, though the low-pressure volume will be 2.25 times the high pressure. At $\frac{1}{4}$ stroke the total volume will be

$$.08 + .75 + .35 + .18 + (\tfrac{1}{4} \times 2.25) = 1.92 \text{ volumes},$$

and the pressure $122.72 \div 1.92 = 64$ pounds.

Similarly at $\frac{1}{2}$ stroke the pressure will be 55 pounds,
at $\frac{3}{4}$ " " " " " 48.3 pounds,
at full " " " " " 42.9 pounds,

and so on for other points so that the whole expansion curve may be determined. In practice there will be a difference of about one pound between the back pressure in the small cylinder and the forward pressure in the large one, due to the friction of the steam in ports and side-pipe. On the next stroke, the head end of the high-pressure cylinder will take in a fresh charge of steam while the crank end of the low-pressure will exhaust its steam into the condenser. The crank end of the small cylinder and the head end of the large one act together in the same manner as described above, so that the pump is double-acting.

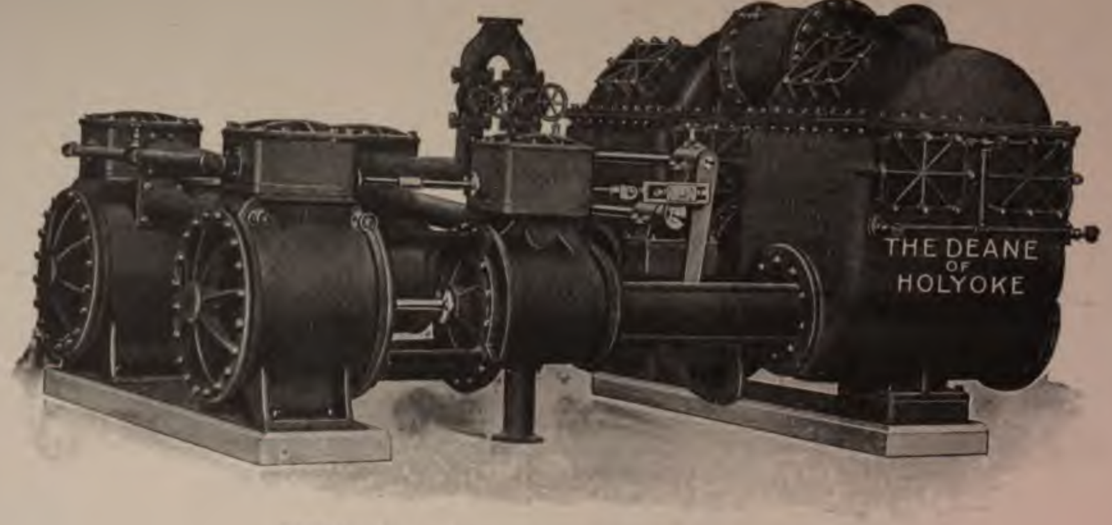
We are indebted to a paper on "Power of Compound Pumping Engines," by John W. Hill, published in *Engineering News*, for the proportions given in Table VIII:

TABLE VIII.

Ratio diameter l. p. cylinder to h. p. "	1.50	1.60	2.00
High-pressure cylinder volume taken as	1.00	1.00	1.00
High-pressure clearance volume.......	.063	.063	.06
Intermediate space volume............	.339	.339	1.12
Low-pressure cylinder volume.........	2.25	2.56	4.00
" " clearance "	.112	.128	.204
No. expansions intermediate chamber..	1.319	1.439	2.250
No. expansions l. p. cylinder...........	1.825	2.020	2.258
No. expansions, total..................	2.400	2.907	5.081
Ratio Mean Effective pressure to (initial pressure minus back pressure).......	0.729	0.682	0.466

Setting the valves on a pump is for the most part a simple operation, and requires only that the valves shall be adjusted, usually by trial, until the pump makes the longest stroke possible without striking the heads, and reverses evenly at the ends of the stroke.

The fly-wheel pump is adjusted by moving the eccentric on



COMPOUND DUPLEX PUMP FOR TANK SERVICE.
The Deane Steam Pump Co.

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TILDEN FOUNDATIONS

the shaft and the valve on its stem until steady running is secured, the same as for any slide-valve engine. The Knowles pump has the stroke lengthened by lowering the roll E, Fig. 50, and shortened by raising it; equalization of reversal is effected by lengthening or shortening the link L as may be required.

Adjustment of the Deane pump is made entirely by moving the tappets on the valve rod; the block A should be clamped to the piston rod in such position that when the piston is at mid-stroke the link B will be vertical. With the valve in mid-position the tappets should be placed so that they are equidistant from each end of the sliding collar, and then adjusted by trial until the working is satisfactory. If the piston strikes at either end, move the tappet at that end towards the collar; if reversal comes too soon at one end, move the tappet away from the sleeve at that end.

For the Dean Bros.' pump the same directions apply as to the Deane, but the stroke may be changed by moving the bolt B, Fig. 53, in its slot without changing the tappets.

The adjustment of the Blake valve is also the same as that for the Dean Bros.', but the tappets on the valve rod should be so set that the valve will have a little lead and open before the main piston reaches the end of its stroke. It has this lead by virtue of the action previously explained unless it is set to be very late in action.

In the Davidson pump, Fig. 55, the valve is adjusted for length of stroke by moving the bolt in the slotted end of the oscillating arm; shortening the leverage shortens the stroke and vice versa. To equalize the reversal, the sleeve which is clamped to the piston rod may be shifted towards the end at which it is desired to quicken the reversal, or a slight adjustment may be made at the point where the oscillating lever is made fast to the rock-shaft which drives the cam C.

For a single compound pump the valves are adjusted in the same way as for a simple pump of the same make. There is an adjustment in the connection between high- and low- pressure valves, and this must be set, with the steam-chest covers off. so that the main valves open at the same time.

All the valves of the duplex pump are set square so that, with

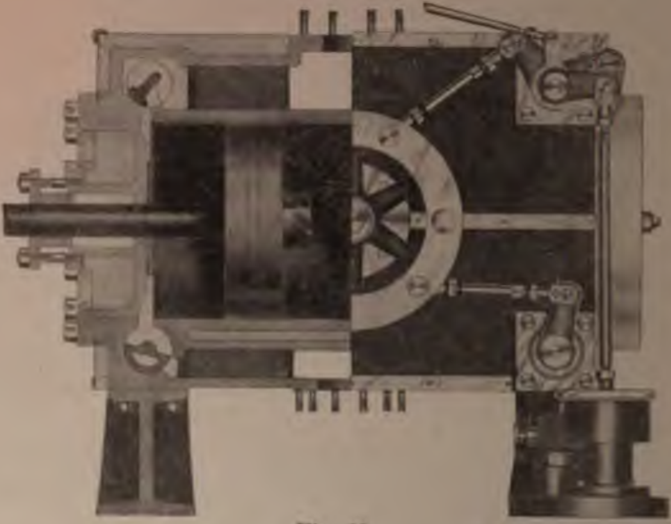

Fig. 62.

Fulton Corliss Cylinder.

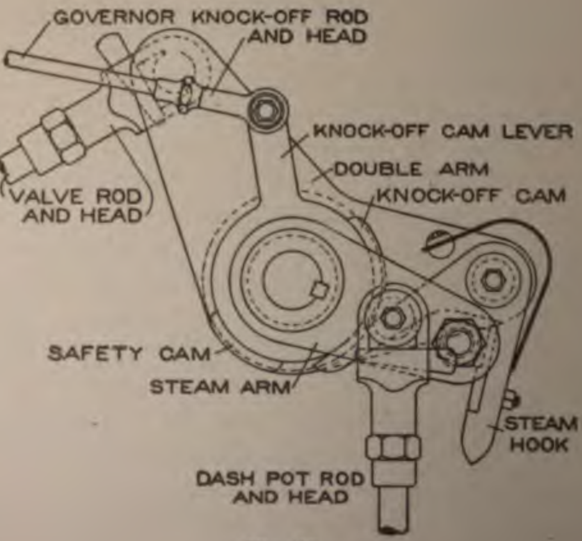

Fig. 63.

both pistons at the middle of the stroke, the valves will be in mid-position, the rocker-arm levers will be vertical and the lost motion will have equal play at each end. The amount of lost motion needed, where it is adjustable, can be determined only by trial, but generally should be as great as possible without having the pistons strike the heads. This will give a long stroke.

For the large pumping engines used in city water-works, the steam ends are designed the same as for any steam engine; and fly-wheels, main shafts and eccentrics are provided for steadying the motion, allowing of expansive working and operating the valves. For such engines the Corliss valves and valve motion have been most commonly used in the United States.

The arrangement of the motion and the action of the valves is shown in Fig. 62. The wrist plate is moved by the eccentric through a reach-rod, rock-shaft and eccentric rod, and from it links run to cranks which turn the rotating valves in their seats. The exhaust valves are positively driven, but the admission valves are so arranged as to be disconnected from the control of the link at some point in the stroke (depending on the position of the governor) by a trip motion, one form of which is shown in Fig. 63.

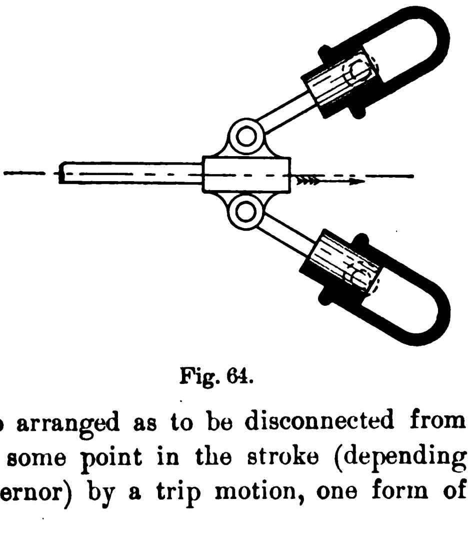

Fig. 64.

Another device used to allow of expansive working of steam in large pumps is the hydraulic compensator, Fig. 64. The steam must work against the pressure of the pistons up to half stroke, and is assisted by it beyond that point, so that cut-off may take place at half stroke, or later, and the energy of expansion be used beyond that point. With this device, there is no shaft or eccentric, and valves similar to those described for duplex pumps are used.

ERECTION AND PIPING.

The location of a pump should be chosen with two principal objects in view: To have the pump itself convenient for running, and accessible for repairs or adjustment; and to keep the piping as short and direct as possible. For a pump to which the liquid is raised by suction there is the limitation that it must not be placed more than 25 feet, and should not be more than 20 feet, above the source of supply; but aside from this, a matter of first importance is to have the machine where it will naturally be kept in good condition. Too often a pump is placed in a dark corner where it is never seen, seldom visited, and always neglected; it soon becomes dirty and leaky, decreasing its efficiency and shortening its life. The second point with respect to piping is often controlled by the layout of other apparatus quite as much as by the position of the pump itself; yet by careful study of the conditions it is often possible to find one place better than others for the pump. It is of more importance to avoid bends and elbows in water piping than in that for steam, because steam makes sharp turns with less friction loss than does water. If hot water is to be handled, the water should flow to the pump by gravity or under pressure. Otherwise the water will turn into vapor under the suction force and the pump will draw in either vapor alone or a mixture of vapor and water.

It is well to place a boiler feed pump in such a position that the gauge glass can be seen when standing at the pump, but this is not absolutely essential, and should be sacrificed if any gain in arrangement of piping or convenience of attendance can be secured thereby. If a condenser air-pump is so placed that the water from the condenser flows to it by gravity, it is possible to maintain a better vacuum in the condenser.

Wherever the pump may be located, a substantial foundation should be provided if the pump is of large size, especially if it is to be run at high speed. It is often sufficient to fasten a small pump to the floor or to heavy brackets secured to a wall, but a pump larger than a 4 × 6 should have a separate foundation. In designing the foundation, remember that the object is not so much to hold the pump up as to hold it down, to keep it from vibrating.

It is, therefore, better to have a foundation deep and narrow than broad and shallow, unless the pump is large and the soil very sandy.

The pump should be well bolted to the foundations in order to prevent vibration, as such movement not only is communicated to the pipe and thence to the building, but tends to loosen the joints in the piping and the pump itself. Absolute rigidity on the foundations should be secured at any cost.

The material may be stone, brick, or concrete, preferably the last. Stone is expensive and difficult to work; brick is liable, unless carefully laid with cement mortar, to be loose and lack compactness; while concrete is easily put down, is inexpensive and has all the solidity of stone. It should be made of good cement mortar, two parts sand to one Portland cement, mixed with broken stone not over 2 inches in longest diameter, in equal parts of stone and mortar. The concrete should be well compacted into a mould the shape of the foundation, the bolts being built in with plate-iron washers on the heads; the concrete should be deposited in layers about 6 inches deep and well rammed, a second layer being added before the upper surface has hardened. This process is repeated until the foundation is completed. It will generally be sufficient to finish the top with a surface of cement mortar carefully leveled and allowed to harden before setting the pump, but sometimes a cast-iron base-plate is used, and this gives a somewhat neater appearance.

As previously stated, the piping should be as short and direct as possible. In large work, the water pipe should have long-bend elbows and tees, and gate valves should be used to reduce the friction. Each pipe should be pitched throughout its length to one point so that it may be drained to avoid freezing; a drain-cock should be placed at the lowest point to remove the water. For water piping, it is well to use galvanized or brass pipe to avoid pitting or corrosion. Covering the pipes which carry cold water will prevent sweating and the consequent unpleasant dripping.

If the plant is one where a shut-down would be serious, a duplicate system should be installed, pump, piping and all; for any plant it is well to provide an injector as relay, in case the boiler feed-pump will not work. In some cases duplicate piping is installed, but this seems hardly necessary, as piping is not likely to get out of order if well taken care of.

Wherever a long column of water is to be moved in either suction or delivery pipes, it is well to place a check valve near the lower end of the column to resist any tendency of the water to back up when the pump reverses or shuts down. In the suction system this valve would be placed on the inlet end of the suction pipe and is known as a foot valve, Fig. 65. For the delivery pipe, it is well to use a check valve near the outlet from the pump and another near the end of the pipe, especially if pumping against high pressure. The check valves may be of either flap or disc type, but if of the latter they should have ample area so that the double turn made by the current of water will not cause great loss of head. The flap valve is shown in Fig. 66 and the disc form in Fig. 67.

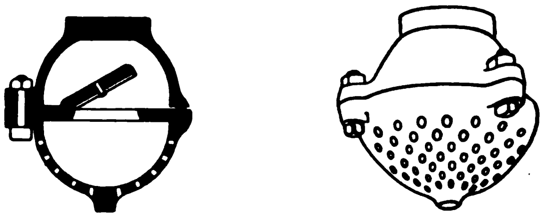

Fig. 65.

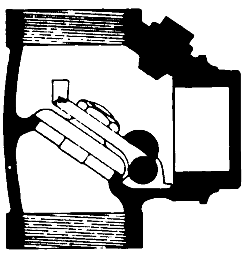

Fig. 66.

For all pumps which are to handle water from ponds, rivers or other sources where sticks, leaves, or any form of rubbish is likely to collect, a strainer as shown in Fig. 65 should be placed on the end of the inlet pipe. The combined area of the openings into the strainer should be 3 to 4 times the area of the pipe. As rubbish quickly collects on a horizontal strainer, the surface should be either slanting or vertical, and should be so designed that the screen may be easily cleansed. The straining surface should be fine or coarse in mesh according to the material to be screened, and made of woven wire or perforated metal as may be most convenient. Often the foot valve and strainer are combined into a single piece. If the lower end of the suction pipe is not accessible for cleaning, and if the debris is of such nature that it is likely to clog the openings, it will be better to use a design given by Barr (see Fig. 68) placed near the pump.

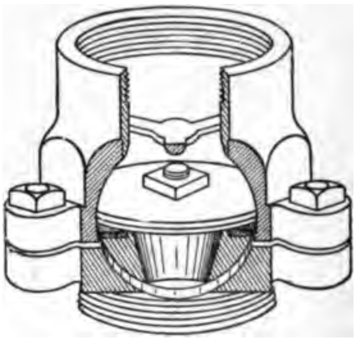
Fig. 67.

The sizes of pipe needed for the suction and delivery are determined by the pump maker and the pipes should never be made smaller than these; if the runs are long, the pipes may well be made larger.

The velocity allowable is, of course, the point which determines these diameters. For the suction, this is usually taken at 200 feet per minute or less; for the delivery-pipe it may be 400 feet per minute or less.

The suction pipe should be of the same size throughout in order to avoid eddies and changes of velocity. Where the pipe is larger than the pump connection, the reduction should be made by a conical pipe with an easy taper, placed next the pump. The greatest care should be taken to see that all joints in the suction system are absolutely tight, as even a small leak greatly reduces the capacity and efficiency. The diameters of pipe suitable for direct-acting pumps are given in Table IX, the suction velocity being allowed at 150, and delivering velocity at 300 feet per minute.

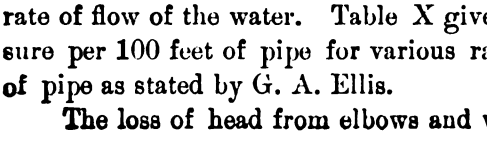
Fig. 68.

The loss in head depends on the length of the piping and the rate of flow of the water. Table X gives the loss in pounds pressure per 100 feet of pipe for various rates of discharge and sizes of pipe as stated by G. A. Ellis.

The loss of head from elbows and valves depends also on the

TABLE IX.

SIZES OF SUCTION AND DELIVERY PIPES.

Diameter Water Cylinder.	Diameter Suction Pipe.		Diameter Delivery Pipe.	
	Single Pump.	Duplex Pump.	Single Pump.	Duplex Pump.
4 inches	2½ inches	3½ inches	1¾ inches	2½ inches
5 "	3 "	4 "	2 "	3 "
6 "	3½ "	5 "	2½ "	3½ "
7 "	4½ "	6 "	3 "	4 "
8 "	5 "	7 "	3½ "	4½ "
9 "	6 "	8 "	4½ "	6 "
10 "	6 "	8 "	4½ "	6 "
12 "	7 "	10 "	5 "	7 "
14 "	9 "	12 "	6 "	8 "
16 "	10 "	14 "	7 "	9 "
18 "	12 "	16 "	9 "	12 "
20 "	12 "	17 "	9 "	12 "

Suction velocity, 150 feet per minute.
Delivery velocity, 300 feet per minute.
Piston speed, 100 feet per minute.

rate of flow, and is most conveniently referred to the length of pipe which would result in the same loss.

The resistance to flow of water in pipes due to bends, elbows, tees, etc., is stated by Foster in his "Electrical Engineer's Pocket Book," to be expressed by the equation:

$$P = F \frac{v^2}{64.4}$$

in which P is the loss in pressure in pounds per square inch, v the velocity of flow in feet per second, and F the coefficient of friction, which varies with the angle of the bend according to the following table:

Angle.	20°	45°	60°	90°	120°	135°
F	.020	.079	.158	.426	.806	.940

A globe valve will produce the same loss of head as two 90-degree bends, and a gate valve a loss equal to that from a 45-degree bend.

If water is known to contain lime or magnesia, it is certain that pipes will fill up more or less from the deposit of scale, and allowance should be made for this in the first place by using extra large pipe.

In choosing the size of steam pipe the same general principle applies; the exhaust pipe, like the suction, should be short, direct, and of ample cross-section. A velocity of 6,000 feet per minute is allowable in the steam pipe and 4,000 in the exhaust.

Care should be taken to have all piping which carries steam pitched away from the pump to avoid the collection of the water of condensation in the steam cylinder, and drips should be provided wherever there is any chance for water to collect.

The use of air chambers has already been discussed. They are usually a good investment if high speed or long pipe runs are to be used. The gain in durability and saving of repairs to the pump and piping system will more than pay the interest on the small cost of ample air chambers.

TABLE X.

FRICTION OF WATER IN PIPES.

Friction loss, in pounds pressure per square inch, for each 100 feet of length of different sizes of clean iron pipe discharging given quantities of water per minute.

G. A Ellis, C. E.

Gallons per Minute	SIZES OF PIPES—INSIDE DIAMETER														
	¾ in.	1 in.	1¼ in.	1 in.	2 in.	2½ in.	3 in.	4 in.	6 in.	8 in.	10 in.	12 in.	14 in.	16 in.	18 in.
5	3.3	0.84	0.31	0.12	0.05										
10	13.0	3.16	1.05	0.47	0.12										
15	28.7	6.98	2.38	0.97	0.30	0.11									
20	50.4	12.3	4.07	1.66	0.42	0.15									
25	78.0	19.0	6.40	2.62	0.51	0.21	0.10								
30		27.5	9.15	3.75	0.91	0.33	0.11								
35		37.0	12.4	5.05	1.20	0.45	0.17								
40		48.0	16.1	6.52	1.60	0.52	0.22								
45			20.2	8.15	2.00	0.65	0.28								
50			24.9	10.0	2.44	0.81	0.35	0.09							
75			56.1	22.4	5.32	1.80	0.74	0.17							
100				39.0	9.46	3.20	1.31	0.33	0.05						
125					14.9	4.89	1.99	0.53							
150					21.2	7.0	2.85	0.69	0.10						
175					28.1	9.46	3.85	1.00							
200					37.5	12.47	5.02	1.22	0.17						
250						19.66	7.76	1.89	0.26	0.07	0.03	0.01			
300						28.06	11.2	2.66	0.37	0.09	0.04				
350							15.2	3.65	0.50	0.12	0.05	0.02			
400							19.5	4.73	0.65	0.16	0.06				
450							25.0	6.01	0.81	0.20	0.07	0.03			
500							30.8	7.43	0.96	0.25	0.09	0.04	0.017	0.009	0.005
750									2.21	0.53	0.18	0.08			
1000									3.88	0.94	0.32	0.13	0.062	0.036	0.020
1250										1.46	0.49	0.20			
1500										2.09	0.70	0.29	0.135	0.071	0.040
1750											0.95	0.38			
2000											1.23	0.49	0.234	0.123	0.071
2250												0.63			
2500												0.77	0.362	0.188	0.107
3000												1.11	0.515	0.267	0.150
3500													0.697	0.365	0.204
4000													0.910	0.472	0.263
4500														0.593	0.333
5000														0.730	0.408
Comparative Discharging Power of Pipes	.5	1	1.75	2.76	5.66	9.88	15.59	32.	88.2	181	316.2	498.8	733.4	1024.	1375.

Care should be taken, however, that no pockets are formed in the piping where air may collect, as the air cushion thus formed will serve no useful purpose, but will reduce both the capacity and the efficiency of the pump. The suction pipe should have a continuous rise from the source of supply up to the pump; and if an inverted U loop must be formed in the delivery piping it should have a pet cock inserted at the highest point so that whatever air collects may escape.

CARE.

After the valves of a pump are properly adjusted, the three things which ordinarily require care are: The lubrication, the packing, and the draining of cylinders. If these matters are carefully attended to, the pump will cause very little trouble.

For the smaller sizes the steam end is generally lubricated by means of a grease cup, which is filled with some form of tallow compound. As the heat of the steam melts this compound gradually, it flows into the steam-chest and is carried by the steam to the cylinder. For larger sizes, a regular cylinder oiler is used, or sometimes an oil pump driven by a lever from the main piston rod. In large plants, the pumps as well as the engines are fed from a central tank into which the oil is forced under pressure by a single large oil pump, and whence it descends by gravity to the various cylinders and passes through sight-feed oilers.

The stuffing box on the steam end usually gets sufficient lubrication from the cylinder, and the one on the water end gets water enough except when the packing is set up hard; then a little machine oil with graphite in suspension will help.

In the case of the steam-cylinder as for any other engine, the less oil used, so long as the piston works quietly, the better.

Flake graphite put into cylinder oil usually settles to the bottom of the cup, but if blown into the steam pipe so as to be carried along by the steam, it will work into the crevices in valves and piston rings and aid materially in reducing the oil required. Also if sifted over the packing when filling the stuffing boxes it will reduce the friction considerably.

For the bearings of valve motions, machine oil is, of course, used. These parts need the same care as any other machine bearings.

The packing in the water piston wears but slowly; nevertheless it should be regularly inspected to make sure that there are no leaks, as they would seriously impair the economy of the pump. Once in two months is not too often to examine the water pistons, and oftener should be the rule if there is any reason to suspect trouble. In repacking, or in tightening up either piston or stuffing boxes, there should be as little pressure as possible, above the limit to prevent leakage.

The piston ring packing of the steam end will wear for years if properly adjusted and lubricated. An inspection once a year is sufficient unless suspicious action in the cylinder seems to call for an investigation.

The stuffing boxes should be kept tight, but not screwed up so as to bind. It pays to be rather generous both in the amount of packing used in a stuffing box and in frequency of renewals; the former because a long bearing between rod and packing will keep tight with less pressure than a short one; the latter because old, hardened packing requires a heavy pressure to force it to a tight joint, and results in a large amount of energy wasted in overcoming friction. For stuffing boxes, any good square packing will answer, but the one on the water end is better filled with some form having a rubber compound for its main body, while that on the steam end works better with a flax packing, as the steam soon kills the rubber. Stuffing boxes should be refilled as often as twice a year, if the pump is in constant service.

The valves in the steam end have a sliding bearing, and will ordinarily wear to a true and tight joint. At the time of the yearly inspection, the head should be removed, steam turned on, and the valve worked back and forth by hand to make sure that no steam passes into the cylinder except when the admission valve is properly open. If the valves leak, they must be scraped to a bearing. Usually the valve face is scraped accurately by using a surface plate, and the seat is then scraped to fit the valve.

The valves in the water end may be reseated by grinding the seats and faces with tools made for the purpose, if both the valves and seats are of metal. If the valves have a bearing surface of composition, as is now the usual practice, the composition disc will wear rather than the seat, and the disc may be renewed easily and at slight expense. Some makers use discs of soft alloy which are more durable than composition and also have its advantages.

In discussing the subject of capacity, the matter of speed was taken up. Manufacturers conventionally rate their pumps at 100 feet per minute, but this is not a good basis, and sixty double strokes seem to be more logical for computation. The object is to reduce slip and prevent pounding; hence, if special devices are used for opening and closing the water valves and to prevent slamming at the end of the stroke, there is no reason why a speed may not be used approaching that of power engines. The slip occurs almost entirely at the ends of the stroke and during the seating of the valves, so that it is always well to use a long stroke even though the diameter be somewhat small.

If mechanically operated valves together with high speed are used, ample air chambers should be placed on suction and delivery systems, as otherwise there is likely to be water-hammer due to the sudden stoppage of the column of fluid in the pipes when the valves close.

There is no difficulty with the steam end in using high speeds provided the steam is kept free from water. This necessitates, in the case of large pumps, a separator in the steam pipe just above the pump, to remove all water and ensure the passage of none but dry steam.

It is impossible to forewarn against all difficulties which may arise in running a steam pump, because it is always "something different" which happens, but trouble can often be traced to certain common faults. Defective valves in the water end and stoppage in the suction pipe are the probable causes for irregular working of a single pump. If the pump slams on one stroke and is steady on the other, it may be that the discharge valves are stuck open on one end either by friction or the lodgement of some substance on the seat. Often a jar with a hammer will remedy this defect, but it is advisable to take off the valve-chamber cover to find the reason for the sticking. If the slamming is on both strokes, it is generally due to stoppage in the suction pipe, or, in the case of a pump newly erected, it may be that the suction is too small. If the latter is the case, slowing down will stop it; but if there is stoppage, the pump will slam at all speeds. If the suction is small, the addition of a suction air chamber will sometimes be beneficial. Slamming may also be due to a leak in the suction system in either valves or joints, or to a leak in the piston packing. Occasionally the springs on the inlet valves are too strong, though this is seldom the case. When starting up, air in the pump may cause it to slam, the remedy being, of course, to prime the pump and suction pipe by pouring in water, and to make sure, by opening the air cock on top of the water end, that all air is forced out of the valve chamber.

If a pump sticks at the end of the stroke, it is due to friction or improper valve setting. In the former case, relieving the pressure on the nuts which set up the glands to the stuffing boxes, until there is just enough pressure to prevent leakage, will overcome the difficulty. In the latter case the valve motion should be so adjusted as to act earlier in the stroke, but it is best to keep the stroke of the pump as long as possible in order to reduce the loss from clearance in the steam cylinder.

In starting up, particularly in cold weather, there will be considerable condensation in the cylinders, and water will form rapidly. This must be given a chance to work its way out through the drips which should be left open until the pump runs free and without sign of water in the steam; the warming up should be done at slow speed.

If a cylinder oiler is used it should be opened up a sufficient time before the pump is to be started, so that it may be ready to act immediately when the pump starts, as the lubrication is needed when the cylinder is cold, even more than at any other time. It is well to have a hand-forcing oil pump connected to the steam pipe of large pumps unless the feed of oil is by a positively-driven pump, so that in starting up, or in case of emergency, a supply of oil may be ensured.

Before starting, the suction and outlet valves should be inspected to make sure that both are open. If a start is made with these closed, it is likely to bring a pressure on the systems which will open the joints.

If the pump is a large one and is run condensing—that is, exhausting into a condenser—the condenser should be put in operation first by starting the flow of cooling water and the air pump.

When these are both working well and a good vacuum has been established, the main pump may be started.

In closing down, the lubricators may be closed a little before the time to stop. The drips on the steam cylinder should be opened after stopping in order to carry off the condensation from any steam which may remain. The drips on the water cylinder need not be opened unless there is danger of freezing, in which case the whole water system should be drained. For this purpose the piping should all pitch toward the pump so that the water may all be drawn off at that point.

In the duplex type of pump, unless the packing be adjusted with even pressure on both sides, the side on which the tighter adjustment is made is liable to "short stroke;" in fact this is usually the trouble with a pump which goes "lame" on one side. If the short stroking is on one end only, it is probably due to poor setting of the valve-motion tappets. Short stroking may also be due to tight packing on the water piston, in which case it can be remedied by taking out the packing and cutting off a little. This is likely to occur only with pistons packed with square packing, as those having the cup leather packing or piston rings adjust their own pressure between piston and cylinder.

In setting up a new pump, it is important to blow out all pipes before making the connections, in order to make sure that no chips or dirt get into the pump. Unions should be provided on each pipe near the pump, so that, in case of suspected stoppage of the pipe it can be readily inspected.

TESTING.

The power used by a pump is usually so small an item in the running expense of a plant, that a test is considered unnecessary; and also the steam exhausted is often used for heating feed water or for some industrial process. If this is possible it is usually an economical way of running; but in plants where many pumps are needed, and where heating feed water is the only use for the exhaust steam, more steam will be available than can be used to good advantage; this is especially true if the main engines run non-condensing. An economical pump is then of great importance.

Duty. In order to determine the good or bad performance of a pump, it is necessary to test it for efficiency and slip, the test being known as a "duty trial." The duty of a pump, as the term descended to us from the days of Watt's early pumping engines, was the number of foot pounds of work produced by 100 pounds of coal. This is a convenient basis for comparison of engines, but is not accurate, as coal varies so much in heat value; also this method of reckoning involves the efficiency of the boiler as well as that of the pump. As an attempt to eliminate the latter source of error in making comparisons, a conventional assumption has been made of 10 pounds of steam evaporated per pound of coal; but this is really only the substitution of one error for another, for a pound of steam when measured in heat units is by no means a constant, and a pound of coal seldom does evaporate 10 pounds of steam in actual boiler performance. The more logical method of comparison is by the duty per 1,000,000 heat units furnished to the pump, a basis proposed by a committee of the American Society of Mechanical Engineers appointed to formulate a code for conducting such tests.

The duty of the pump is found by measuring the quantity of water delivered and the height through which it is lifted, or its pressure equivalent. The coal or steam used must also be measured. Then

$$\text{Duty} = \frac{Q\,H \times 100}{C}$$

in which Q = pounds of water delivered,

H = head against which the pump works, both suction and forcing, and

C = pounds of coal burned.

Or on the new basis.

$$\text{Duty} = \frac{Q\,H \times 1{,}000{,}000}{B\,T\,U}$$

where Q and H are as before, and B T U is the heat units in the coal or steam, whichever is measured.

An inaccurate method of computing duty is sometimes used, which is based on the area of the water piston or plunger and its travel; but this takes no account of the slip, which may in small pumps be as much as 20 per cent; hence it is to be condemned.

The slip is found by comparing the water actually delivered with the total piston or plunger displacement, for the time of the test. The difference, measured as a per cent of the piston displacement, is the slip.

The water delivered is measured either by weighing, by the use of calibrated tanks, by a weir, or by some form of meter. One of the first two methods is best for small pumps, and the meter is practically the only means available for large ones where the delivery is into a closed pipe system. For the weight or tank method, the arrangement of Fig. 69 is used, one tank being filled while the other is being emptied, through a quick opening gate valve. If the water is weighed, a certain amount as nearly as may be is run into the tank and the exact weight is caught after the valve is closed and the water is flowing into the other tank. For calibrated tanks, the filling is done nearly to a set mark, at which the capacity of the tank is known, and the exact level is found by dipping from the second tank. The weir can be used only where the delivery is into an open vessel, as the current of water must be made to flow over an open notch as in Fig. 70. The amount of water which passes this notch evidently depends on its length, and on the head of water above the sill. There is a certain contraction as the water enters the notch; but if the edges are beveled to a sharp edge up stream as shown, this will be slight. The depth of the notch should be not over $\frac{1}{2}$ the length, and is better made considerably less, say from $\frac{1}{10}$ to $\frac{1}{4}$. The over-fall below the notch should be at least twice the depth of the notch. The head of water over the sill should be measured at a point some distance back of the notch in order to get a quiet, even surface.

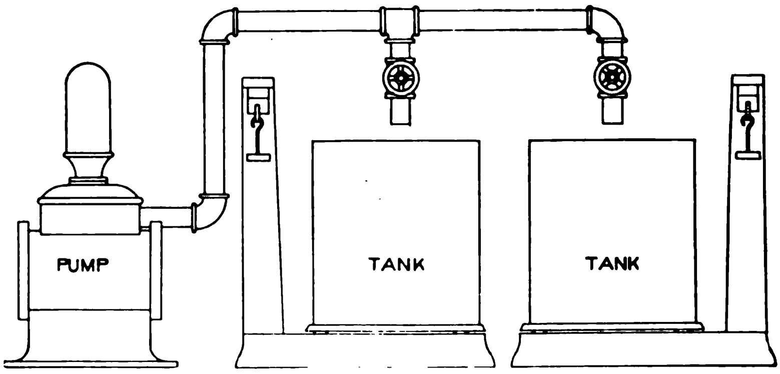

Fig. 69.

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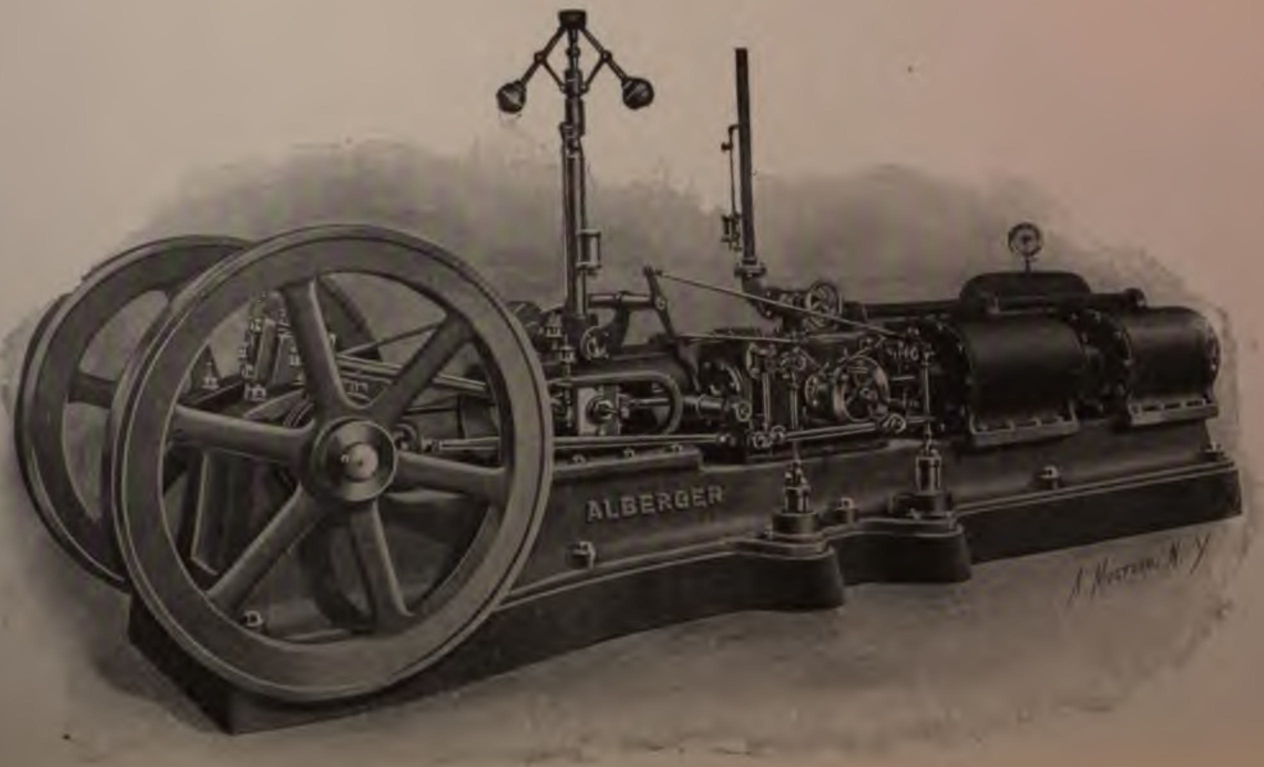

CORLISS TWO-STAGE DRY VACUUM PUMP.
Alberger Condenser Co.

Any method of measuring the head will answer which gives it accurately; but a hook gauge, such as shown in Fig. 71, will give the best results. The reading of the gauge should be taken when set so that the point just breaks the surface as it is brought up from below, when no water is flowing over the notch. This gives the height of the sill from which to calculate. When the water is flowing from the pump, a reading from the gauge is again taken as the point just breaks the surface. The difference between the two readings is the head above the sill.

The flow, if there were no end contraction, would be $Q = b\,v\,h$ where Q is the cubic feet per second, b the length, h the head of water above the sill, and v the velocity in feet per second. But $v = \sqrt{2\,g\,\frac{h}{2}}$ the same as for falling bodies, $\frac{h}{2}$ being used because it is the head of center of flow. It has been found by experiment that there is a contraction at the ends and bottom of an opening, due to the in-rush of the water from all sides, and that the flow will be about .62 the theoretical amount; hence

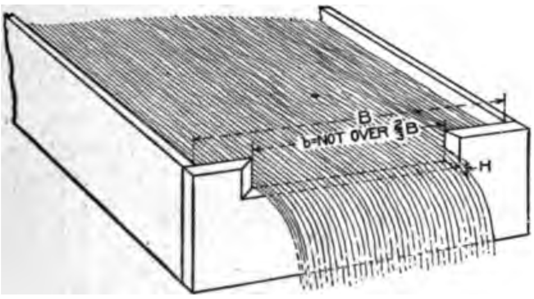

Fig. 70.

$$\begin{aligned} Q &= .62\ bh \sqrt{2g\,\frac{h}{2}} \\ &= .62\ bh \sqrt{gh} \\ &= .62\ bh^{\frac{3}{2}}\ g^{\frac{1}{2}} \end{aligned}$$

but g is the acceleration due to the force of gravity and is equal to 32.16; hence $.62 \times g^{\frac{1}{2}} = 3.52$ and $Q = 3.52\ bh^{\frac{3}{2}}$.

It is found, however, that for accuracy the formula must be modified to take account of the depth of the water, and also that the coefficient is too large. Smith gives, in his Hydraulics, the equation

$$Q=3.29\left(b+\frac{h}{7}\right)h^{\frac{3}{2}}$$

which is accurate for weirs for depth h, from 6 inches to 2 feet and with length b, not less than $3h$. For large quantities of water which must be delivered under pressure, the Venturi meter is the most accurate means of measurement. This is a patented device manufactured by the Builders Iron Foundry of Providence, R. I., and registers the flow by means of a recording mechanism driven by clockwork. The next best device is some form of rotary water meter, carefully calibrated. These will work well with cold water, but are not to be relied upon with hot water as the varying temperatures affect the readings appreciably.

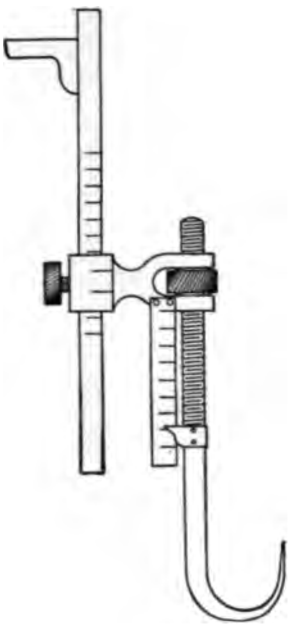

Fig. 71.

For methods of testing large pumping engines, the student is referred to the report of the committee of the American Society of Mechanical Engineers, Vol. XI of the Transactions, which can be obtained from the Society in pamphlet form at nominal cost.

The following discussion will be confined to small pumps :

For a power-driven pump it is necessary to measure the power supplied. If belt-driven, this can best be done by means of a transmission dynamometer, which measures the pull on the belt. Then this pull in pounds times the speed of the belt in feet per minute equals the foot pounds per minute; and that quantity divided by 33,000 gives the horse power. The work performed per minute will be the weight of water pumped per minute times the distance through which the water is raised as indicated by gauges on the suction and delivery pipes near the pump. These heads can be derived from the ordinary pressure gauge readings by the table on page 9. The work per minute divided by 33,000 gives the delivered horse power. For a motor-driven pump the power applied can readily be obtained by electrical measurements. Measure the voltage and amperes of current with the pump carrying its load and then Voltage $\times \frac{\text{Current}}{746}$ = Horse power. From an efficiency curve of the motor as supplied by the makers, or obtained by a dynamometer test of the motor, get the efficiency at the horse power thus found. Multiply the horse power by the efficiency and the product will be the power supplied to the pump.

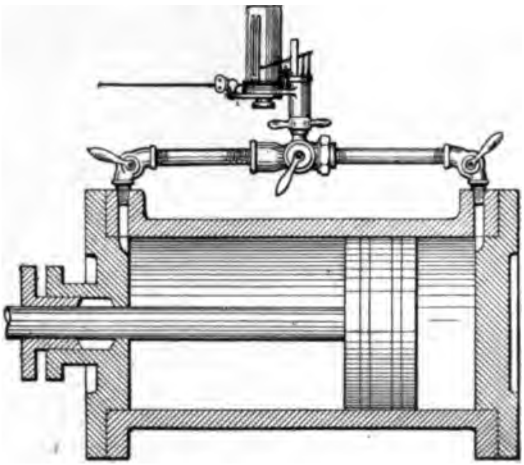

Fig. 72.

The power delivered by it in the form of water pumped is found by the same method as for the belted type.

For a steam-driven pump it is necessary to attach an indicator to the steam end in order to measure the power supplied by the steam. The indicator is connected as shown in Fig. 72, to register the pressure in the cylinder at each point of the stroke. The average of these pressures is then found, measuring between the lines indicating the steam and exhaust pressure as shown in Fig. 73. The sum of lines 1, 2, 3, 4, etc., divided by the number of lines gives the average length, and this multiplied by the scale of the spring, or pounds pressure represented by an inch of height, will give the average effective pressure. The scale of the indicator spring is always found stamped on the cap at one end of it. This average pressure multiplied by the area of the piston in square inches, by the length of the stroke in feet and by the number of double strokes made per minute, gives the work done per minute in one end of the cylinder. In the same way pressure times area, times length, times number of strokes, gives the work for the other end, and the sum of these amounts divided by 33,000 gives the horse power developed. It should be noted that there is a difference between the areas of the two ends of the piston owing to the insertion of the piston rod in one end.

Sometimes the work done in the water cylinder is measured by using the indicator in the same way as described for the steam end. The work done by the water piston can, of course, be found by this method; but there is nothing to show whether the work is used in pumping water or in slip and leakage, except that a slow seating of the valves may show in a reduced average pressure from the diagram, as in Fig. 74.

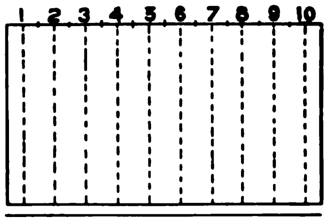

Fig. 73.

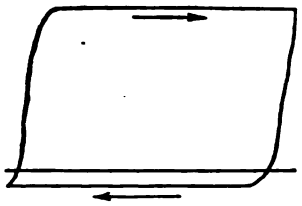

Fig. 74.

To test the leakage past the piston, one cylinder head may be removed and the pump run single acting, the water which passes the piston into the open end of the cylinder being caught and weighed. This does not, however, measure the leakage due to faulty valves or seats, and the only way this can be found is by measuring the water actually pumped.

The slip is then found as follows: Multiply the area of the water piston by its length of stroke and by the number of single strokes if single acting, or double strokes if double acting—all dimensions being taken in feet—to get the number of cubic feet of water which would be pumped per minute as obtained by measurement; subtract the water actually pumped and divide the remainder by the computed volume which should be delivered.

The quotient expressed as a percentage is the slip. Slip is due to the leakage past the piston plunger and through the valves, and the amount varies with the condition of packing and seats and with the promptness of valve closure. It can be kept at a minimum by careful attention to packings, and by running slowly and steadily to allow the valves time to seat.

The efficiency of the pump may be expressed according to various standards. If efficiency as a machine, or mechanical efficiency, is desired, it is found by dividing the horse power utilized in pumping water, by that furnished to the pump by belt, motor or steam cylinder. If efficiency of the water end is wanted, it is found by subtracting the percentage of slip from 100. The total efficiency is the mechanical efficiency multiplied by the pump efficiency.

To find the "duty" the work done in a given time is found by one of the processes already indicated; the heat furnished during that time is computed from the coal burned and the efficiency of the boiler, or better, by condensing the steam used in a surface condenser, weighing it and calculating the heat needed to evaporate that amount of steam, starting with water at the temperature of the exhaust steam. Reduced to the form of equations this becomes:

$$\text{Duty} = \frac{\text{Foot pounds of work done.}}{\dfrac{\text{Heat units used}}{1{,}000{,}000}}$$

Foot pounds work = weight of water multiplied by equivalent head overcome. Heat units used = Pounds of steam used × (total heat at initial pressure minus the heat of the liquid at exhaust pressure).

The values inside the parenthesis must be obtained from tables of the properties of saturated steam, which are given in "Boiler Accessories," works on the steam engine, or engineering handbooks.

For a power-driven pump the duty is found by the formula:

$$\text{Duty} = \frac{\text{Foot pounds of work done.}}{\dfrac{\text{Foot pounds furnished the pump.}}{778 \times 1{,}000{,}000}}$$

since 778 foot pounds are equivalent to one heat unit.

The pressure needed bears a ratio to the pressure due to the total head of lift and immersion varying from 0.77 for comparatively shallow wells (100 feet or so deep) yielding large volumes of water, to 0.62 for wells 500 feet in depth and having but a small flow. Obviously the lowest air pressure which will do the work is the most economical, since any excess of pressure is used up in producing unnecessary velocity of discharge at the outlet.

The efficiency increases as the ratio of submergence of the lower end of the discharge pipe below the water-level to lift above the water-level increases. There is much disagreement as to the efficiencies that can be obtained; but tests seem to indicate that an efficiency ranging from 18 per cent (for a ratio of 1.5 submergence to lift) up to 37 per cent (for a ratio of 2.6), the efficiency being based on the power required to compress the air, is as much as can be expected.

A great deal depends on the proper proportioning in size of air pipe to discharge pipe, and of submergence to lift. A cross sectional area of water pipe 6½ times that of the air pipe has been found satisfactory; and a submergence of twice the lift is common in practice, though some tests seem to indicate that a ratio of submergence to lift of 3 to 1 would give better results. The ratio should not in any case be less than 1.5 to 1.

In this connection it should be remembered that the water-level when pumping will always be lower than when at rest, and the above ratio should be fixed for the level under working conditions.

If the air pipe be too large, more air will be furnished than is needed and the discharge velocity will be too great; if the air pipe be too small the air bubbles will not expand sufficiently to fill the discharge pipe but will rise through the water without pushing it along upward.

A velocity not exceeding 20 feet per second is recommended in the air pipe.

The machinery necessary for an air-lift system comprises the following: an air compressor of size sufficient to give the needed air supply, a reservoir large enough to break up the pulsations from the compressor and steady the flow, gauges and valves for regulating the pressure, and the necessary well piping.

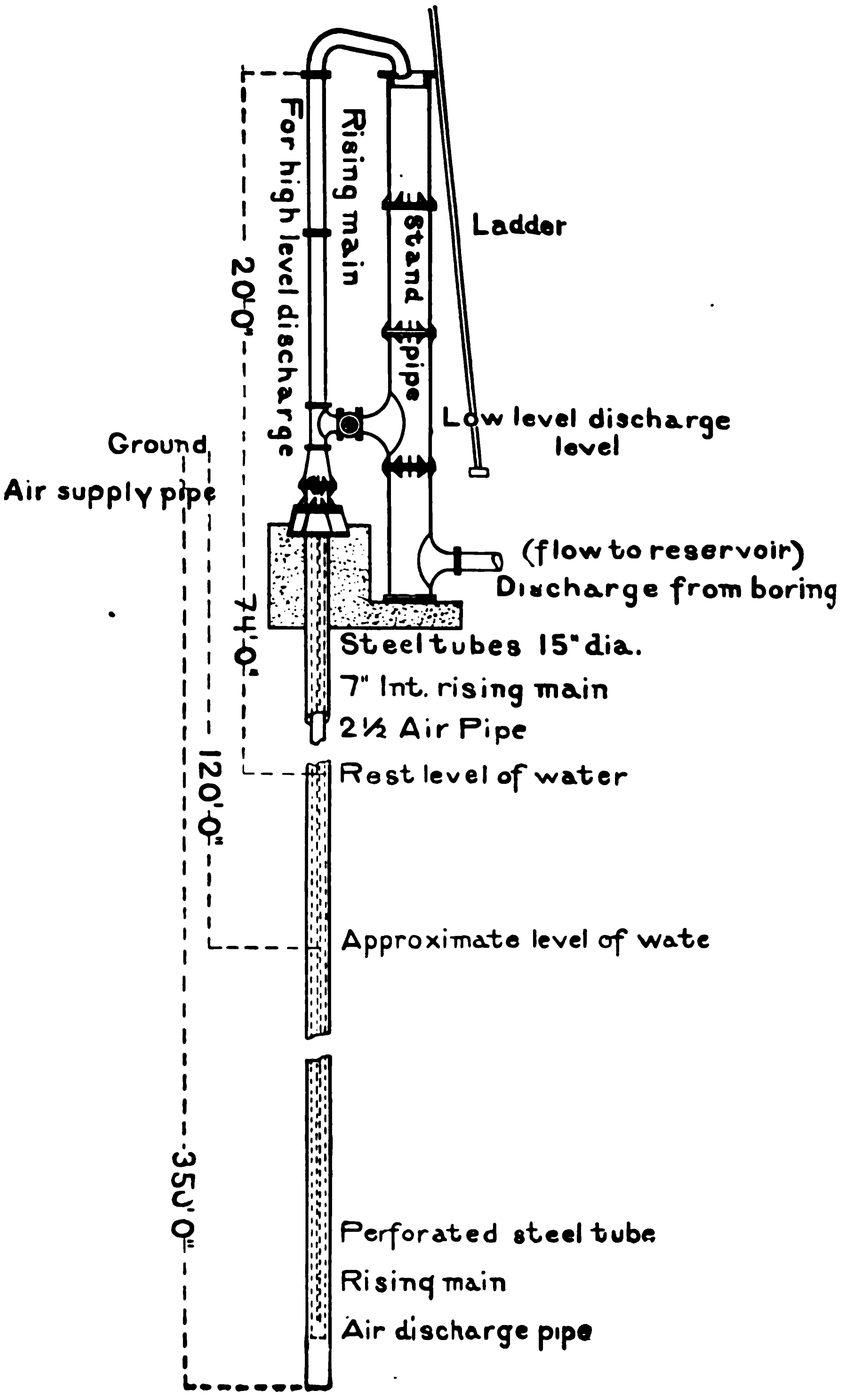
Rising main
For high level discharge
Stand pipe
Ladder
20'0"
Low level discharge level
Ground
Air supply pipe
(flow to reservoir)
Discharge from boring
74'0"
Steel tubes 15" dia.
7" Int. rising main
2½ Air Pipe
Rest level of water
120'0"
Approximate level of wate
350'0"
Perforated steel tube
Rising main
Air discharge pipe

Fig. [illegible]

For pressures up to 60 pounds, a single-stage duplex compressor will answer; for pressures between 60 and 300 pounds a two-stage compressor, with an inter-cooler between cylinders, will be found economical; while for pressures above 300 pounds a three-stage compressor should be used.

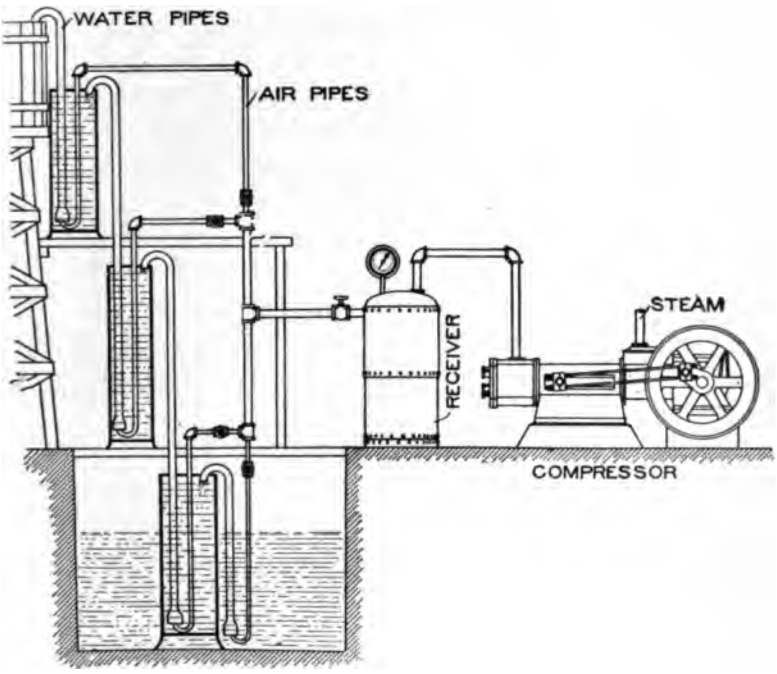

Fig. 77.

The supply of air needed will vary with the lift, and of course with the quantity of water handled. Wm. H. Maxwell gives the following equation:

$$V = \frac{G \times L}{20}$$

where V = cubic feet of free air per minute.
G = cubic feet of water per minute.
L = lift of water in feet.

The arrangement of air pipes and discharge pipes is largely one of convenience. The least friction will be produced by admitting the air to the bottom of the discharge pipe as shown in Fig.

75; but in deep wells this is often inconvenient, and the air pipe is carried down inside the water pipe as in Fig 76.

For high lifts it is sometimes convenient to use multiple-stage arrangements as shown in Fig. 77, the object being to secure sufficient depth of immersion without the expense of drilling a very deep hole. Only one air compressor is needed, as the pressure can be controlled by throttling the valves for the lower stages without serious loss of economy.

The advantages of the air-lift system are its simplicity, its concentration of all machinery into one place which can be conveniently located, and its ability to handle water containing grit, stones or ashes without injury to the machinery. On the other hand the efficiency is low, and a great depth of well in proportion to the lift is needed. The air-lift system is not adapted to all classes of service, but for handling a number of scattered wells, or a single deep well in an awkward location, it is simple and effective.

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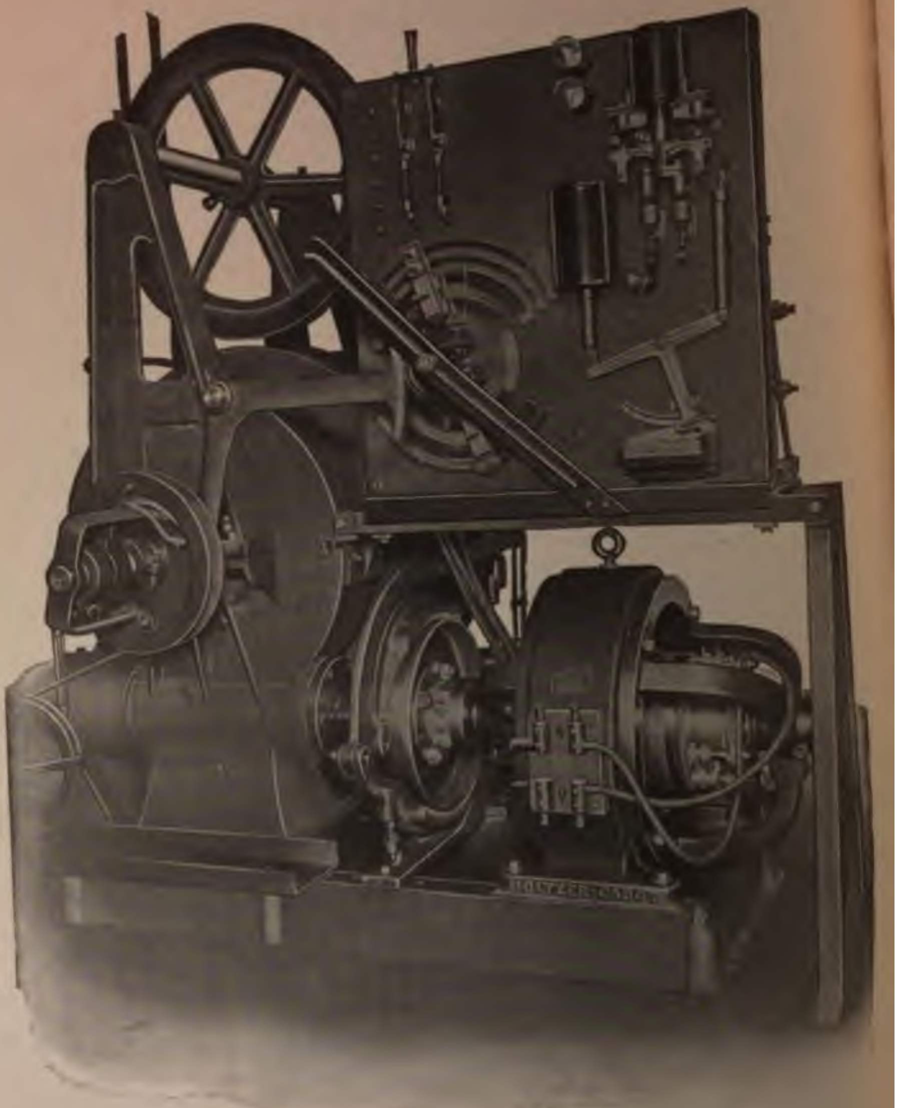

MOTOR DIRECT-CONNECTED TO ELEVATOR.
Holtzer-Cabot Electric Company.

ELEVATORS

The elevator as a modern appliance has become a very important factor in business life. Fifty years ago it was comparatively unnecessary, and in the few instances in which it was in use, it was considered more of a luxury than a necessity. The earliest form of elevator was used only for merchandise, and the power employed was derived from a revolving shaft through the medium of leather belts running over pulleys. The introduction of steam, however, as a source of power for its operation, made a change in the speed that could be attained, and enlarged considerably its field of operation. It then began to be used for passengers as well as goods.

EARLY STEAM ELEVATORS

The application of steam for this purpose was made in a modified form, the engine employed being a double cylinder engine with the cranks set at right angles to avoid centering, but the valve motion was the principal feature of difference. Of course, many experiments were tried in the beginning, but what we shall describe here is that form of valve motion which became generally adopted. The distributing valves were of a special type, resembling more than anything one ordinary D-valve within another, and the number of ports in the cylinders were four each; Nos. 1 and 3 being the usual distributing ports carrying steam to each end of the cylinder, and Nos. 2 and 4 being used alternately as steam and exhaust ports. The starting and stopping was done by means of a change valve, which alternately, at the will of the operator, converted one of the latter mentioned ports into a steam supply port and the other into

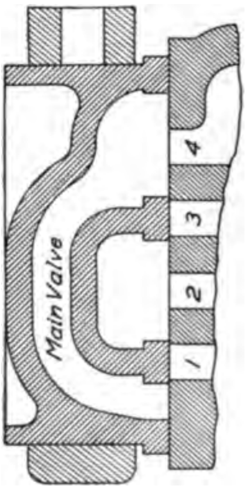

Fig. 1. Distributing Valve.

an exhaust. These valves — one change and two distributing — were all three contained within one steam chest, and the pressure of the steam from the boiler was always on them, holding them to their seats. The change valve, however, was the only one which opened a port directly into the steam chest. The operation of these valves and their arrangement will be readily seen by reference to the accompanying illustration.

It will be seen from the illustration that with this arrangement of valves there could be no lap or lead in the distributing valves on the cylinder faces, because the valves had to act alternately for steam supply and exhaust, and any lap or lead that might be given them for operation in one direction would produce a distorted action when used for running in the reverse direction. The consequence was that the engine of this type was not economical in its use of steam; and while it was a great favorite at the time of its introduction, and for many years afterward (because of a lack of anything better) it has, since the introduction of the

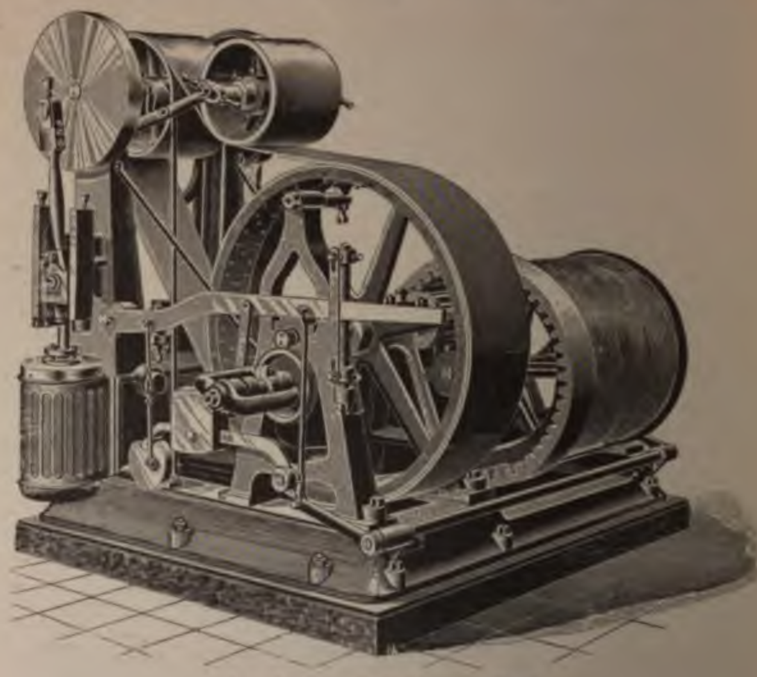

Fig. 2. Spur-Gear Elevator Engine

hydraulic and modern types of electric elevators, almost gone out of use.

At the time of its introduction it was used entirely in connection with spur gearing, the first types of this engine being made to drive a pulley on the crank shaft which was belted to a larger pulley running in stands on the engine bed, the shaft which this pulley drove having on its end a spur pinion meshing into an internal gear, which was bolted to the end of a hoisting drum or spool which wound up the cable or wire rope, to one end of which the traveling platform or cage was attached. This wire rope passed from the hoisting drum up the hatchway and over grooved wheels or sheaves at the top of hatchway and then down to the cage, and the change valve, by means of which the steam was shut off or turned into the engine to operate it in either direction, was connected to a wire rope of smaller diameter, which led up the hatchway within easy reach of the operator, and the pulling of this rope up or down was sufficient to start the elevator in either direction.

The amount of steam, however, under pressure, required to operate the engine when lowering a load, was so much less than that needed for hoisting, that in order to prevent the engine from racing and lowering at an undue speed, the change valve was always adjusted to give a very small opening into the steam supply when running in this direction, and in addition to that a certain amount of lap had to be given to the valve on the exhaust side, so as to choke the exhaust and thereby retard the descent. There was some danger of overloading of the engine, for in case an overload was placed on the cage, of course an attempt to lift it would fail, but in lowering, especially when the steam was shut off quickly, the pressure of the confined steam in the cylinders would sometimes exceed that in the steam chest, in which case the distributing valves on the cylinders would be lifted from their seats, and where they were fitted to work in a yoke or buckle, at the end of the valve stem, they would remain off the seat, when once lifted therefrom, until replaced. There was nothing then to hold the load but the brake, and to obviate this trouble it was customary in many cases to bolt to the bottom part of the steam chest an angle piece fitting closely at the back of the valve. This piece being stationary, and its vertical side parallel with the cylinder face, the valve worked up and down between it and the valve seat, and it prevented the valve from being raised from its seat.

The brake used on this type of engine was a flexible band of steel, which was lined with hard maple in short sections and fastened to the band by screws. A suitable lever for applying the brake, with a heavy cast-iron weight on the end of the lever and proper adjustments for taking up the wear, completed the outfit. The brake was always applied by means of the weight on the end of the brake lever and was released by means of a heart-shaped cam fastened to a pedestal or stand on the engine bed and operated by the yoke or automatic stop, which, being connected to the operating cable in the hatchway, before described, was always actuated when the hand cable was pulled to the center of its throw.

The pistons of these engines were usually very simple in construction; they consisted of a disc or block of cast iron properly bored and fitted to the piston rod and turned with grooves to receive the piston rings, which were then sprung over the block into their respective grooves. They were made slightly eccentric, being thicker on the side which was left uncut, and were usually turned little larger than the bore of the cylinder. When they were cut, a piece had to be taken out, leaving a space of about $\frac{3}{16}$ inch between the cut ends, and the rings consequently had to be squeezed together or compressed in order to enter the ends of the cylinder, and this caused a constant outward pressure of the piston rings. They were made two in number; in some cases three, and were usually from $\frac{3}{8}$ to $\frac{5}{8}$ inch wide.

Owing to the confined space into which these engines had to be put at times, it became necessary to reduce them somewhat in height in order to get them into low basements when desired. The consequence was that the connecting rods were not always as long as the best practice would dictate, and as a consequence of this, and the constant reversing of the engine, it was frequently found somewhat difficult to make them run quiet. Now, however, with care, this result can generally be attained.

Another cause of hammering in this type of engine was a lack of care on the part of the manufacturer to so proportion the length of bore of cylinder as to allow the outer piston rings to just pass over the end of the bore at the end of each stroke. This length of bore, of course, was determined at the time of counterboring the cylinders, and where the bore was so long that the piston rings did not quite reach the ends of it, they would in time, as the bore of the cylinder enlarged from constant wear, leave a shoulder at each end. Against this shoulder the rings would strike at the end of each stroke, and if the engineer was not posted on this peculiarity, he would probably try for months to get his rods to run perfectly quiet without good results. The only remedy in a case of this kind would be to take out the pistons and file the shoulders, before mentioned, but it would be only temporary. The proper way to get rid of the evil entirely would be to counterbore the cylinders a little more, but it was a job that was attended with considerable difficulty with the engine in place, hence the first method would be found most satisfactory.

The cross heads and guides were similar to those of most engines, whether horizontal or vertical, and differed with the ideas and taste of the maker. Several different arrangements were used; some with plain straight slides, some with V-shaped; but the most popular was that of the bored guides, for cross heads, using a bronze shoe with proper adjustments for wear. These engines would often run as high as 500 r. p. m. at full speed.

One feature of this engine which frequently caused great annoyance was the running off of the belt which connected the pulley on the crank or engine shaft with the large pulley, before mentioned, running on a shaft in stands on the bed. There would seem at first sight to be no good reason why a belt of this kind should not run well and in line, but frequently carelessness in workmanship was the cause of this, for if the pulleys themselves were of equal diameter at each side, and the shafts were not perfectly aligned with one another, it would cause this trouble; and while the belt might be adjusted to run well in one direction, it would run off the pulley when the engine was reversed, there being a "tightener" for the purpose of taking up the slack of the belt, which could be adjusted so as to cause the belt to run well in one direction. The distance between centers of shafts being short, the belt was necessarily short too, seldom exceeding 10 feet in entire length, and it was always endless, that is, without seam or lacing.

The writer has frequently seen on some of the older types of these engines a pulley that was larger on one side than the other; this also would cause the trouble.

Another defect in this engine was the liability, when the belt had been in use a great while and neglected, for it to become dry and cracked, and if it broke either when lifting or lowering a heavy load, there was a chance of the cage falling, there being nothing to hold it in that case but the brake. To automatically apply the brake and at the same time shut off steam, in case of an accident of this nature, there was attached, to one of the arms carrying the idler, a vertical rod The lower end was attached to the cam operating the brake; the upper part of this rod was hollow and the lower part telescoped into it. A collar and set screw on the lower rod being set in the proper position would receive the end of the upper rod on its face, in case the belt should break or come apart, for the great weight of the idler pulley would cause it to fall, carrying the arm to which the upper part of this rod was attached. This then would throw the brake cam around in the position to apply the brake, and at the same time shut off the steam, thus stopping the engine also.

This pulley, which performed the double office of tightener and as an adjustment for the direction of the belt, was very necessary, because as the belt stretched from constant use, this idler, running on top of it, and being made very heavy for the purpose, would take up the slack of the belt, causing it to have greater contact with the pulleys. The arms, which carried the shaft upon which it ran, were attached to the upper part of the engine frame and extended outwards toward the rear of the engine, and were of such a length as to leave the pulley in the right position upon the belt just between the engine pulley and the larger pulley in the stands on the engine bed. Sometimes, however, a sudden stoppage of the engine would cause this tightener to jump away from the belt and then drop back upon it, and this feature had a tendency to cause the belt to break whenever it became weakened in any part.

To prevent this jumping of the idler, which also had a bad effect on the stopping of the engine, spiral springs were sometimes attached to these arms and carried down to a convenient point below where they were attached either to the bed of the engine, or to the wrought-iron braces which stayed the upright frame to the bed. Turn buckles were provided to give the springs proper tension, and this remedied the difficulty just related.

When these engines were at rest the steam chest was always full of steam and ready at any moment to start upon the change valve being opened in the proper direction. As this steam chest radiated considerable heat, there was always more or less water of condensation in it. A drain pipe was run from the bottom of the steam chest to a steam trap, which was set considerably below the level of the bottom of steam chest, and the water escaped to this steam trap.

The automatic stop was a screw provided with a traveling nut and adjustable set collars. This screw was a sleeve which usually ran upon a long stud bolted to one of the stands in which the larger pulley shaft ran, and it was geared to the pulley shaft by means of a spur gear and pinion, which were so proportioned as to give this automatic screw about the same speed as the drum shaft. The traveling nut was so arranged that at either end of the run it would

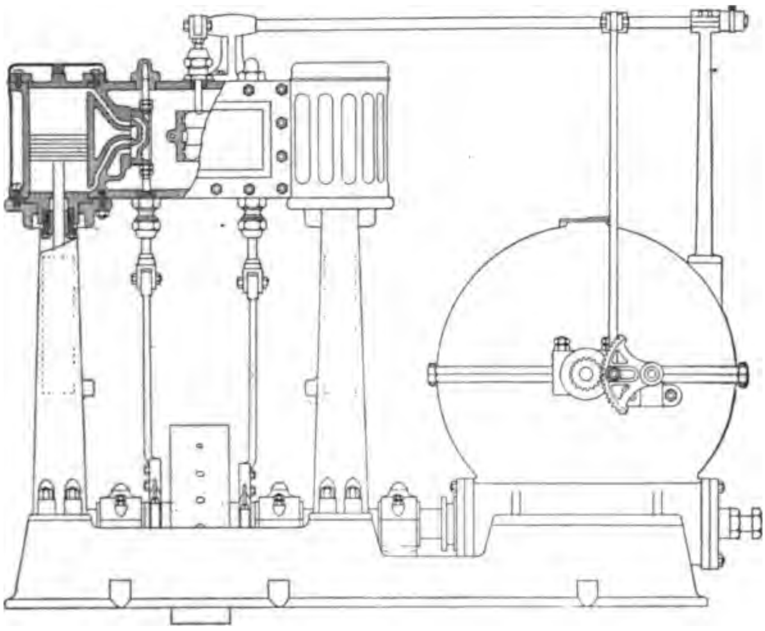

Fig. 3. Elevator Engine with Worm Gear.

come in contact with the set collars, which had to be set just to the right position to gear with this traveling nut. They each had a tooth which interlocked when the traveling nut and collar were brought together. By this means, the traveling nut was made to revolve, and as it turned, the automatic yoke, which was connected to the starting lever by means of a link connection, operated the change valve and applied the brake at the same time, thereby stopping the engine at the limit of its run. This end was also attained by means of stop buttons on the operating cable, which were made so as to clamp the cable wherever they were placed and tightened up, and a striker or arm attached to the cage so as to slide up and down on the operating cable freely. Whenever the striker came in contact with one of these stop buttons it pulled the cable the same as the attendant would, and thereby also shut off steam and applied the brake. The operations were identical in each case, except in the method of arriving at results. A pressure of from 60 to 90 pounds of steam was usually carried at the boiler.

The lubrication of the wrist and cross head pins, eccentric straps, etc., was usually supplied by means of compression grease cups. This method was adopted on the score of economy and cleanliness; the valves were lubricated by means of a self-feeding cylinder lubricator.

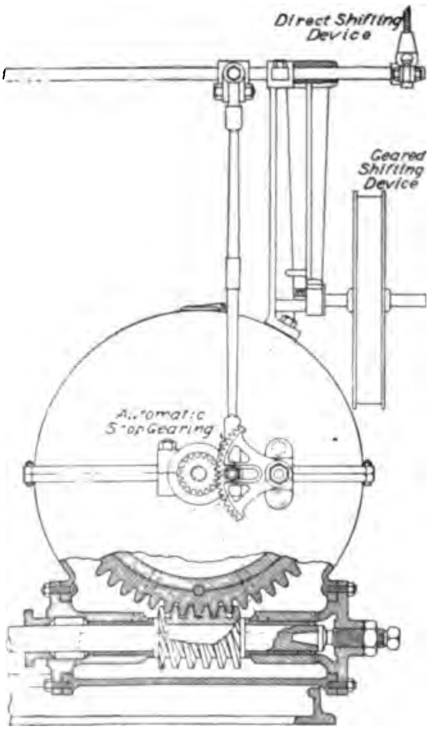

Fig. 4. Worm Gear in Housing.

The chief difficulty with the spur gear type of engine was that of low pressure and overloading. It sometimes happened that when there was no steam on the engine at all, the car being left at one of the upper stories, an ignorant attendant would put load on the car and pull the operating cable. The brake being released, the load would run the engine backwards and run to the bottom violently. Of course, when these engines and their peculiarities became well known, accidents of this kind were less frequent, and taking it altogether, the service rendered by these engines was invaluable. Being the most rapid up to the time of their introduction and for a long time afterward, they were a favorite for many years, the principal objection to them being the cost of operation in comparison with other methods introduced later.

Later on a modification of this engine was used for passenger service. The changes consisted of the use of a worm gear in place of the spur gearing just described, and owing to the location of the worm shaft it necessitated the use of an engine with the cylinders inverted, and placed at the top of the engine instead of below as in the original form. This arrangement has some advantages for passenger work, as the liability to run down, which always exists with a hoisting machine where spur gearing is used, was eliminated. It was also considered safer and more desirable for passenger use on account of its smoother action and the fact that the breakage of one or two teeth in the gear would not cause the platform to descend rapidly. The other characteristics of the engine were not changed.

WATER BALANCE ELEVATOR

Contemporary with this engine, which attained its greatest popularity during the 70's, there was introduced a form of hydraulic elevator which at one time bid fair to be a successful rival of the steam engine. It was called the water balance elevator. It consisted of the usual cage or cab in which the passengers rode, the cables necessary for hoisting which passed up the top of the hatchway in the usual manner and over sheaves, thence down into a large metal tube or well hole, and attached to the other end of these cables was a large bucket that nearly filled the well hole just mentioned. At the top of the well hole and above the highest point to which the bucket traveled, there was a tank containing water supplied by means of a steam pump. At the bottom of the bucket was a discharge valve, which as well as the valve at the bottom of the tank just mentioned, were operated by means of pedals located in the cab.

The operator by pressing the appropriate pedal with his foot would discharge water into the bucket from the tank above. When sufficient water had accumulated in the bucket to more than balance the weight of the cage and its occupants, the elevator would begin to move, the water in the bucket forming a counterbalance weight and virtually dropping down the well hole dragging the cage upwards, and vice versa, when the water was allowed to discharge itself from the bucket it would become lighter than the cage and the cage would drop. This water having been discharged into a tank at the bottom of the well hole, would be pumped again into the overhead tank.

The speed of this elevator was unlimited, and was governed entirely by the use of a powerful brake gripping the slides or rails on which the cage traveled. This brake was arranged by means of very strong springs which always held the brake on, and had to be released and held off by hand to obtain any movement of the cab when the conditions for motion were right; and in letting go of the brake, it applied itself with sufficient power to stop the elevator.

This form of elevator was found to be very expensive, both to install and operate, and moreover, was dangerous in the hands of unskilled men, and it soon went out of favor upon the introduction of the horizontal hydraulic elevator. The latter was originally the invention of William Armstrong, a man prominent among mechanical engineers in Great Britain.

HORIZONTAL HYDRAULIC ELEVATORS

The first elevator of this type was used for the purpose of hoisting stones from a quarry in Yorkshire, but its utility as an elevator for merchandise was soon recognized and it began to be used extensively for this purpose in that country, and it was along in the early '70's that it was first introduced into the United States. The earlier machines of this type were usually operated by water pressure obtained from the city mains. The machine consisted of a cast iron cylinder, the bore and length of which varied according to surrounding conditions, being chiefly governed by the water

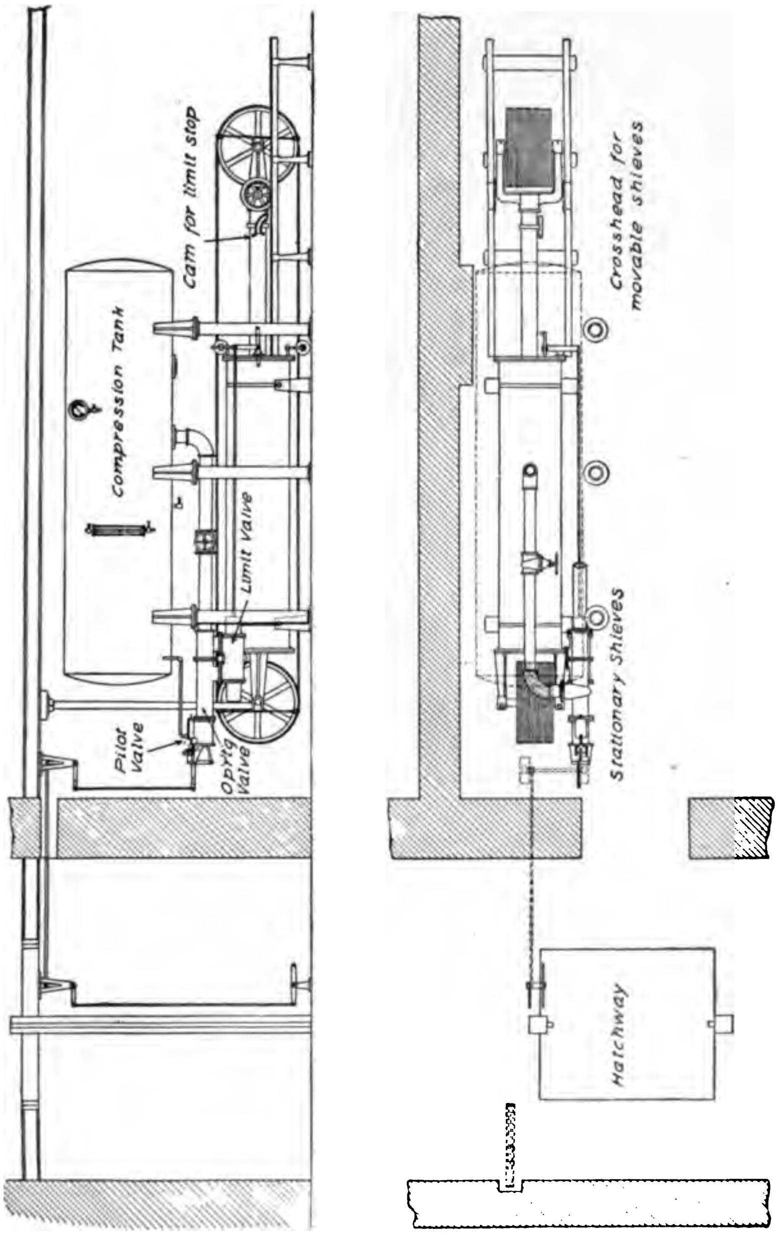

Fig. 5. Plan and Elevation of Horizontal Hydraulic Elevator.

pressure available and the height of the building in which it was used. A piston, fitting closely in this cylinder, was made water tight by means of suitable packing. There was a piston rod and cross head which carried a set of traveling sheaves, and a set of fixed sheaves. The cross head traveled on a track provided for the purpose, which acted both as a support and guide for same. The cable which hoisted and lowered the cage, passed up the hatchway in the usual manner over sheaves at the top of same, thence down to one of the fixed sheaves below on the end of the machine. From there it passed successively along under the machine, around one of the movable sheaves on the cross head, back to one of the fixed sheaves at end of machine and so on three or four times, and the other end was finally made fast to the hydraulic engine. This arrangement of rope and sheaves was exactly like a block and tackle, the cage being attached to the loose or running end of the rope. Now when water pressure was applied to the piston, it would pull these sheaves apart, causing the end of the cable in the hatchway to raise, with the cage attached, at a speed much faster than that at which the piston traveled, the difference in speed being governed by the number of sheaves collectively on the machine. For instance, if the cross head had four movable sheaves traveling with it, and at the fixed end of the machine there were four sheaves, the ratio or difference between the speed of cage and that of the piston would be 8:1; in other words, the cage would travel eight times as fast as the piston, and eight times as far. The ratios more generally used are from 4:1 to 10:1, depending on the speed required and the load to be lifted. With this arrangement when

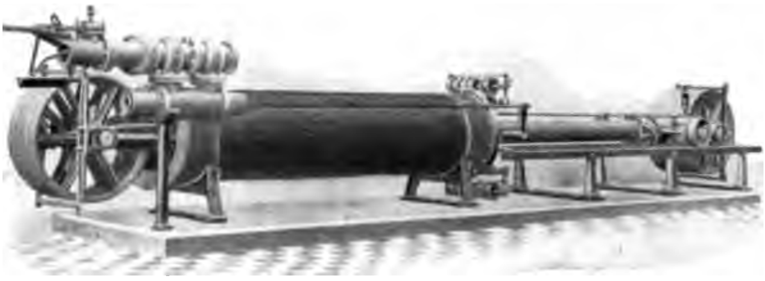

Fig. 6. Horizontal Hydraulic Elevator.

connected to the city mains, the water, after being used, was wasted or allowed to run to the sewer. Later on, the introduction of the roof tank permitted water to be used over and over again, the same as in the water balance elevator. A still greater advantage was gained by the introduction of what was called the pressure tank. This was a modification of the accumulator so much used in Europe in connection with hydraulic presses, and consisted of a reservoir that was fitted with a plunger of large area, which worked vertically through a tight stuffing box, and having on its end an enormous weight or load of cast iron. Water being pumped into this accumulator, raised the plunger with its load, and when draft was made upon it, it would force this water out into the cylinder of the hydraulic ram with a pressure equivalent to that of the load carried.

The pressure tank was similar in arrangement, except that the compression of air above the water gave the pressure required. A cylindrical tank properly braced and stayed was used, with inlet and outlet pipes and water glass to show the height of water in the tank, and a pressure gauge. Air would be pumped into the tank up to a moderate pressure, afterwards water would be pumped in, and this water further compressing the air, would produce an ultimate pressure of anywhere from 100 to 150 pounds per square inch. The inlet and outlet pipes for the water were directly at the bottom of the tank to prevent the escape of any of the air, and when water was drawn off from this tank in the cylinder of the hydraulic engine, the drop in pressure would not be more than a very few pounds, owing to the expansibility of the air above the water, about one-third of the total contents of the tank being air under pressure.

This arrangement enabled higher speeds than was admissible with the street main service, the street pressure of many cities being low; in fact those having a high pressure—anything from 60 to 100 pounds—being rare. Moreover this arrangement had other features which were desirable, the absence of water hammer in the pipes being one, the using of the same water over and over being another, and the ability to have the most useful pressure being a third. With the higher pressure, cylinders of a smaller diameter could be used, and consequently a less amount of water also.

The operation of the hydraulic elevator was by means of a two-way valve, the most improved type of which consisted of a cast iron cylinder with a brass lining, which was perforated opposite the openings or branch pipes in the cast iron body. Inside this brass lining was a plunger with leather cup packings held in position by discs of brass, which were so arranged as to cut off the supply of water gradually so as to produce an even and gentle stop. Where the supply was taken from the city main an additional precaution was taken of using an air chamber on the supply pipe near the operating valve. The office of this was to prevent violent shocks in the pipe from the sudden stoppage of the flow of water through the same, caused by shutting the operating valve quickly. The water in the main, when the valve was closed, would continue its onward course up into the air chamber, the air in which being compressed, would act similarly to a spring, gradually retarding the flow of the water and restoring its equilibrium, but in the case of the compression tank it acted of itself as a huge air chamber.

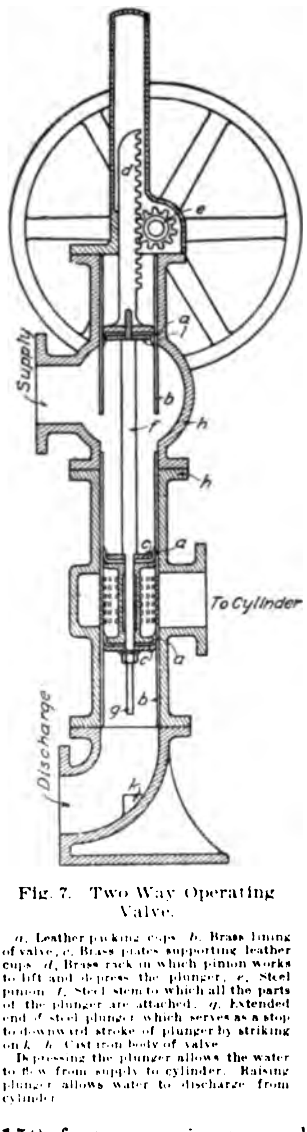

Fig. 7. Two Way Operating Valve.

a, Leather packing cups. b, Brass lining of valve. c, Brass plates supporting leather cups. d, Brass rack in which pinion works to lift and depress the plunger. e, Steel pinion. f, Steel stem to which all the parts of the plunger are attached. g, Extended end of steel plunger which serves as a stop to downward stroke of plunger by striking on k. h, Cast iron body of valve.

Depressing the plunger allows the water to flow from supply to cylinder. Raising plunger allows water to discharge from cylinder.

With the higher pressure obtained by use of the tank, greater speeds could be attained, frequently as high as 300 or 400 feet per minute, while with the street main system it rarely exceeded 150 feet per minute, and frequently was as low as 50. The compression and roof tanks were usually kept supplied with water by means of powerful steam pumps, the change of level of water in the tanks being made to automatically turn on steam or shut it off. These pumps, therefore, were not obliged to run constantly, but only when the supply of water in the tanks became somewhat depleted, the pumps running simply long enough to supply the deficiency.

When the higher speeds were found desirable and attained, some better means of operating the elevators than the hand cable became a necessity, and the invention of the lever operating device followed. With it came the pilot valve. This was a small auxiliary valve attached to the main operating valve which obtained its power from the pressure tank. The operator in the cab moving his lever, would open the small pilot valve, which in turn admitted water to a piston on the stem of the main operating valve, the pressure of the water moving this piston in either direction as desired, and with it the main plunger of the operating valve. The pilot valve itself and its connection with the plunger of the main operating valve is so constructed that a partial movement of the operating lever would produce a partial opening of the pilot valve, and in turn, a partial opening of the main valve, if so desired. The full opening and closing were obtained by the full movement of the operating lever.

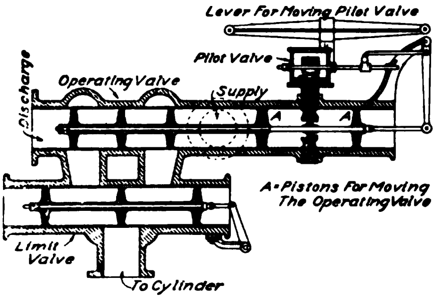
Lever For Moving Pilot Valve
Pilot Valve
Operating Valve
Supply
Discharge
A
A
A-Pistons For Moving The Operating Valve
Limit Valve
To Cylinder

Fig. 8. Auxiliary and Operating Valves.

VERTICAL HYDRAULIC ELEVATORS

The horizontal hydraulic elevator had not been in use very long, when Mr. C. W. Baldwin, of New York, conceived the idea of using a vertical cylinder. This was not entirely new, as they had been used in Europe, but not exactly in the manner in which he proposed to use his. The advantage of his form of hydraulic elevator was that it took up less room in the building, because it could be set up in the same hatchway with the traveling cage, in one corner of the well hole, and for the sake of economy in space it was usually made with a ratio of from 2:1 to 4:1, instead of from 6:1 to 10:1 as with the horizontal hydraulic. The consequence was that the cylinders were necessarily quite long, though smaller in diameter than the horizontal machine. They differed also from the horizontal in the fact that they did not use any guide ways for the cross head.

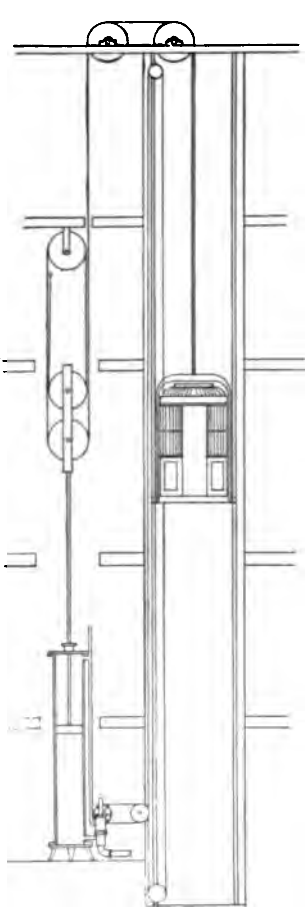

Fig. 9. Vertical Hydraulic Elevator.

The cylinder being set vertical and a fixed sheave directly above it, the end of the hoist cables were made fast to a beam overhead and led thence down to the cross head and around the sheave in same, and up again over the fixed sheave before mentioned, thence over the sheave in hatchway directly above cage. This gave the machine a speed ratio of 2 to 1, and the piston would travel just half the distance of the cage, but it was found that a great loss of pressure occurred at the beginning of the travel, owing to the top of the cylinder being so high above the level of supply. To equalize this, the discharged water was returned through a circulating pipe to the bottom of the piston, instead of discharging it into the surge tank or sewer immediately after it was used. By this means the weight of the water beneath the piston was used to equalize the pressure, but as this water beneath the piston was held there by atmospheric pressure until discharged, it was found that the length of the vertical cylinder could not be more than 33 feet at sea level, or its equivalent in other places. This limited the length of vertical cylinder that could be used, so that the ratio of this type of machine was governed somewhat by this.

But with all these machines, both horizontal and vertical, where the pressure was comparatively low, a great loss of power was caused by the friction of the piston in the cylinder, and the flow of the water through the pipes, as well as the difference in weight of the cables, depending on whether they were hanging in the hatchway on the side of the car or on that of the machine. These cables, which were usually four in number, and sometimes more (and generally of about $\frac{5}{8}$ inch diameter, weighing about $\frac{3}{4}$ of a pound to the foot), would, when the car or cage was at the top of the hatchway all hang down towards the machine, and in the case of a building say 100 feet high would amount to over 400 pounds. Now while as a measure of economy, it was desirable to counterbalance the weight of the cage, it could not be done very closely with this difference in the weight of the cables on one side or the other, according as the cage was at the lower or upper landing. Hence, some means of counteracting this was found desirable, and it was done by hanging chains in the hatchway, one end of them being attached to the wall of the hatchway about half way up the run or travel of the cage, their other ends being attached to the bottom of the cage. It will readily be seen that when the platform or cage was down at the bottom of the run, and consequently the cables on the car side hanging down in the hatchway and equalizing the weight of those on the other side, the chains would be hanging on the wall, but that when the cage was at the top of the hatchway and the weight of the cables preponderating on the other side, these chains would be hanging on the bottom of the cage, thus offsetting the weight of the cables. By this means closer counterpoising could be obtained, and the desirability of this method of counterpoising, in after years, when much taller buildings came into existence, may very readily be seen. In fact, it became quite indispensable in the case of buildings of 17 or 18 stories.

Later on, the introduction of the electric elevator and the claim made for its economy of operation caused elevator builders to look for more economical methods of operating the hydraulic elevators. One of the chief drawbacks to economy in the hydraulic elevator was the fact that the same amount of water had to be used per trip regardless of the load, and the introducers of the electric elevators made the claim that an amount of current proportional to the load carried was all that was used.

The introduction of the high pressure water system in the city of London had attracted considerable attention in engineering circles, and the use of elevators in connection therewith had shown that a greater economy was possible with a higher pressure, owing to reduced area of cylinder, there being less friction and smaller consumption of water. The system of high pressures was introduced here, but it has not realized all that was expected of it. The enormous expense connected with the installation and maintenance are the chief drawbacks, but during the time that was devoted to experimenting with the high pressure systems, one or two types of elevators were evolved that gave considerable satisfaction, one of these being that of using a vertical cylinder with a ram, the weight of which was sufficient to lift the cage with its load. The hoisting of the load, therefore, was done by discharging the water from the cylinder, and when the platform or cage was to be lowered it was accomplished by turning the water pressure against the end of the ram and lifting it. This ram was geared in the usual manner by means of a cross head and sheaves having a ratio of anywhere from 2:1 to 6:1.

Other schemes were devised for economy, one of which was to have two or more tanks at varying pressures, one tank having say 100 pounds pressure, a second 150, and using one or the other according to the load to be lifted, an automatic operating valve being used in connection therewith.

Another form of hydraulic elevator, which has always been very popular in Europe, was the plunger machine or ram. This consisted of a hollow plunger, which passed through a stuffing box in the top of the cylinder which was let down into the ground, the depth of same being the length of run from lower to upper landings, the platform or cage being set on top of this ram. When water was let into the cylinder the pressure of same against the bottom end of the ram forced it up out of the cylinder, and the cage with it, to the top of the building, the lowering being done by allowing the water to afterwards escape. The form of valve and its operation was the same in this case as in that of the other types of hydraulic elevators.

This style, of elevator, however, from the point of economy had one objectionable feature that was peculiar to itself, and which was more noticeable in the higher runs or upper stories of buildings. The plunger being hollow, to insure lightness, had a certain amount of buoyancy when wholly immersed, but when run partially or entirely out of the cylinder, this buoyancy necessarily decreased, and consequently the lifting power of the elevator became less and less as it reached the upper stories of the building. It consequently could not be counterbalanced very closely, because if that were done the plunger, in descending to the lower story, would come to a point where it would stop of itself because of its inability to displace the water in the cylinder. This was a matter that entered largely into the calculation of the area of plunger when arranging the proportions of cylinder and plunger, in relation to the pressure of water to be used.

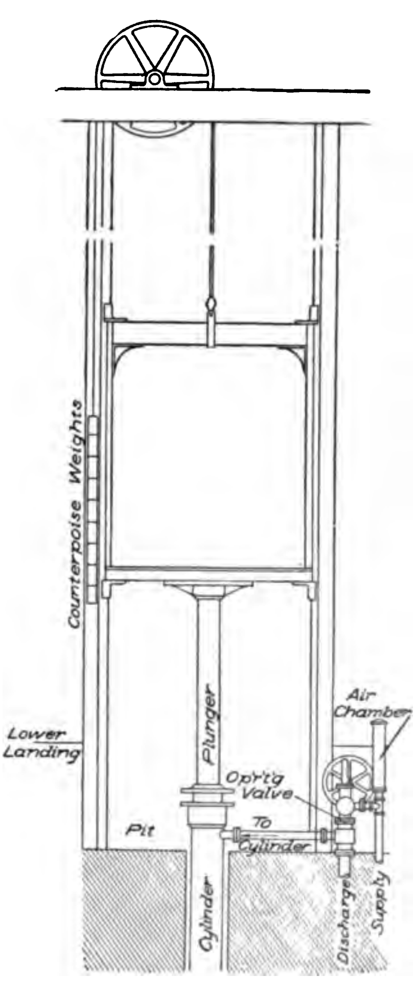

Fig. 10. Plunger Elevator.

The earlier elevators of this type were usually made with a cast-iron plunger, which as before stated, was hollow, and, owing to the brittleness of cast iron, had to be re-enforced by running a heavy wrought iron rod up through the middle of the plunger, the lower end passing through the bottom end of the plunger, the upper end being made fast to the floor of the cage. Without this the sudden opening of the operating valve would allow the escape of water from the cylinder for descent, and when the cage was in the upper story it was liable to cause the plunger to break off. Such an accident as this occurred some years ago in Paris, causing the loss of one or more lives.

In the case just mentioned, the wrought iron rod in the center of the plunger was absent, its absence being a fault in the design of the machine. To-day, however, with the introduction of Bessemer steel tubing, the necessity for the center rod does not exist, the ends of the tubes being threaded internally, and a male coupling being used inside the pipe. The joints in the cast iron plunger were made by boring out the ends of the sections of the plungers and inserting a thimble nicely fitted, which entered each end of the adjacent sections to a distance of 3 or 4 inches, the ends of the sections of the plunger themselves being faced or squared off perfectly in the lathe, and the whole being put together with a hydraulic cement composed of litharge and red lead mixed with boiled linseed oil, or Japan varnish. These machines are very much in vogue to-day for short runs, and despite their lack of economy in operation, which must necessarily exist owing to the conditions described, a company has within the past few years been formed for the exclusive manufacture of this style of elevator.

PACKING AND LUBRICATION

Of course, in the manufacture of all the styles of hydraulic elevators here described, a very important feature is the condition of the bore of the cylinders and the external diameters of the plungers. It is absolutely essential that both cylinders and plungers shall be parallel and smooth, any inequalities or inaccuracy causing a waste of the water used in operating them, and one of the most essential features in their care is the proper, and even, setting up of the packing, both in the glands of the plunger machine and in the piston of the cylinder machine.

Many forms of packing have been devised, the earliest being the leather cup, which is almost as old as the hydraulic press, in which latter it proved to be the most successful packing ever devised. In a hydraulic press, the ram or plunger travels a very short distance and very slowly, and under exceeding great pressure, but with the lower pressures used in hydraulic elevators, and with the greater rapidity and distance of travel of the piston, this style of packing was not found to be as long lived as could be desired. Hence, various other means were devised to overcome the defects found to exist in the leather cup. One of the best was that of using a leather cup exactly as the original, but smaller than the diameter of the cylinder by an inch or inch and a quarter, and to fill up the space between the leather cup and the bore of cylinder, rings of ordinary square pump piston packing, made of alternate layers of rubber and canvas, were used. These were held in place by means of a follower ring, and through the web of the piston leading directly behind the leather cup, small holes were drilled which permitted the water in the cylinder under pressure to obtain access behind the leather. This pressure forced the leather outwards against the aforesaid rings of piston packing, pressing them against the bore of the cylinder, and allowing the passage of the piston in a water tight condition.

This form of packing was used very largely in the vertical hydraulics, described above, and introduced by Mr. Baldwin, but this form of elevator had one great disadvantage over the horizontal type of machine, in that both ends of the cylinder were closed, and these conditions did not permit of proper lubrication. Hence, after machines of this type had run a few years the cylinders became badly scored or grooved, and there was a great leakage of water past the piston, and the only remedy was the reboring of the cylinders. In many cases, especially where elevators of this type had been installed where the water pressure was low, the cylinders had been designed with such thin metal in the walls that they would not admit of reboring. In some cases, engineers had tried to introduce a lubricant in the water used to operate the elevators, but with no very marked success.

With the horizontal machines, however, one end of the cylinders being open, lubrication became an easier problem to solve. In these machines, owing to the greater diameter of cylinder, the leather cup and piston packing was not so readily applied, and in lieu thereof, several forms of packing were adopted by different makers, each having his own particular choice. In some cases, plaited hemp was used. Others used the square piston packing made of rubber and canvas before described. Still others used rubber cord; some used it in the square strips and others round with alternate layers of square piston packing, and each of these had its own particular merits and advocates.

The piston had to be made with an annular space for the reception of this packing, so shaped that the pressure of the necessary follower ring, which was essential to the tightening up of the packing, caused it to be forced outwards against the internal sides of the cylinder. This follower ring was made with a roomy groove in that part of it which extended outside beyond the packing, and from this groove extended a pipe leading out beyond the open mouth of the cylinder to the cross head where a large compression grease cup was fastened and kept filled with grease. The tightening of a screw in this grease cup forced the grease through the pipe into the groove in the follower, thereby keeping the cylinder constantly lubricated at every stroke, and to prevent its escape through the open end of cylinder and consequent waste, a "wiper" or single ring of packing was used with an auxiliary follower ring to tighten it up as required.

There is a peculiarity about the lubrication of the cylinders and plungers of hydraulic elevators not generally known to the persons in charge of these machines, which is that nothing but purely animal oil or grease will give perfect lubrication.

Since the introduction of oils and greases that were partially or wholly composed of products of petroleum, their cheapness and adaptability to revolving shafts and bearings has made them a general favorite, but however well adapted they were for lubrication of this nature, they were wholly unfit where water came in contact with the surface, and that is why they were not suited for hydraulic elevators. Each time the cylinder was filled with water, or when, in the case of the plunger elevators, the plunger became immersed in the cylinder, grease or oil that had been applied during the stroke would float away in the water, leaving the bore of the cylinder or external surface of the plunger entirely bare. To obviate this, it was necessary to use a purely animal oil or grease, which, being a better resistant of water, would remain on the metallic surface for several strokes of the piston or plunger, as the case might be, and consequently was more economical and more satisfactory.

LIMIT VALVES

For limiting the travel of the cage to the upper and lower landings, in other words, to cause the water to be automatically shut off at these points independently of the efforts of the operator, the earlier hydraulic elevators depended entirely on button stops on the operating cable, working in conjunction with a striking arm on the cage.

In all elevators it is the custom, in putting on the operating cable, to arrange it in such a way that pulling down on the standing part of the cable which is used by the operator causes a motion of the elevator in an opposite direction, and vice versa. For instance, were the operator to pull the cable down, the car would rise. Now at a proper place on this cable is fastened a sort of clamp, being made in halves for the greater convenience in putting it on, and the two halves being fastened together with bolts. When put in place on the cable and clamped tightly there, it is immovable except with the cable. An arm of wrought iron is fastened to some convenient part of the cage sufficiently high to be out of the way of the operator, and this arm is formed at one end into a ring which slips freely over the operating cable as the car travels, and strikes the button just described, on arrival at either end of the run, moving the cable exactly as the operator would do it to the central or stop position.

This arrangement worked very nicely and filled all requirements as long as the operating cable was in good condition, but it was found in course of time that, as the operating cable wore or its condition deteriorated from any cause (the principal one being dampness in the pit at lower landing), it was liable to break, and this always occurred when it was least expected, the result being disastrous in every instance. In some cases the piston would come out at the end of the cylinder, allowing the water of the cylinder to escape, causing serious damage, for it would continue to flow through the supply pipe, and at the same time the cage would be run violently into the sheaves at the top of the hatchway, often breaking them and causing other serious damage, and in the case of the plunger elevators, the plunger would come out of the cylinder, allowing the water to escape in like manner.

To prevent this, various expedients were devised, among them being the limit valve. This was an auxiliary valve placed between the operating valve and the cylinder, and was so arranged in the case of the horizontal hydraulic elevator that cams attached to the piston rod at either end—one near the cross head and another near the piston—would engage an arm on a rock shaft, moving the arm so as to cause it to close the limit valve, and thereby prevent the ingress or egress of water to or from the cylinder according as the cage was at the upper or lower limit of its run. The earlier forms of these valves were made single acting, that is to say, they simply closed the pipe between the operating valve and cylinder, and they were so arranged that they did not entirely close it unless the car went a few inches beyond the landing in either direction. When this occurred, the valve had to be opened by hand in order to give the cage headway in the opposite direction, and this was found to be a decided disadvantage.

Then another form of valve was devised of the two-way type, taking water through one passage from the operating valve for hoisting, and discharging it through another from the cylinder through the operating valve also, thus giving the operating valve control of the water at all points, excepting the upper and lower limits of the run. With this arrangement it was possible to run down or up to the extreme limit, allowing the limit valves to take care of the stops at either end, because in this case when the limit valve shut off the supply of water for hoisting at the upper landing, it left the opening for lowering still open and vice versa.

This form of limit valve proved all that was required of it, but even *it* was liable to derangement, so to overcome these difficulties and to make it simply impossible for the elevator to run beyond its limit, more care was taken with having the cylinders of the exact length required for the run, plus the length of the piston, and across the open end of the cylinder and spanning the piston rod, which was allowed to pass freely through it, was a very heavy bar of cast iron, which projected some inches beyond the outer diameter of the cylinder. Similar projections were made on the cylinder head on each side to correspond with the ends of the bar, just described, and running along longitudinally between them were very heavy rods of wrought iron or Bessemer steel threaded at each end. The ends of these rods passed through holes in the lugs cast on the cylinder head and through the ends of this bar, and nuts on the ends of the rods bound the bar and cylinder head together. A rubber bumper was put around the piston rod, clamped there firmly, and set partially in a recess made in the hub of the piston, and upon the arrival of the piston at the end of the run this rubber bumper would come up hard against the heavy bar of cast iron, which being made amply strong for the service it was to perform, prevented the travel of the piston any farther, and in like manner the piston came against the cylinder head of the lower limit of travel, there being a similar bumper of rubber fastened in the recess in the hub of piston on that side. Of course, these cylinder heads had to be strongly re-enforced to withstand the strain, and this was found to answer all requirements, for it would always operate, regardless of whether the limit valve or buttons of the operating cable gave out or not.

In the case of the vertical hydraulics, which were known as the standard elevator, an appliance of this kind was not so easily put on, in fact none was ever devised that acted successfully. The only places they could be used was at the upper end of the run and at the lower end, between the cylinder and operating valve, and this had the disadvantage previously described as existing with the earliest form of limit valve on the horizontal machine. If the valve in the circulating pipe was closed it prevented the elevator from running in either direction; hence, it had to be set so that it would not close entirely, and this very fact impaired its usefulness and effectiveness. In the case of the vertical plunger, however, it was very easily arranged, the cylinder being made so that when the plunger got a little below its lower limit of travel it was made to rest upon the bottom head of the cylinder, and fastened around its lower end was a ring which, when it reached its upper limit of travel, would come in contact with the bottom end of the stuffing box, thereby preventing its ever coming entirely out.

ELECTRIC ELEVATORS

The most popular form of elevator in use to-day is that operated by electricity, and the general arrangement of machines now in use is that of a worm and gear wheel actuated by an electric motor, the gear wheel being attached to a winding drum or spool, the whole machine, of course, being bolted to an appropriate bed plate, and the worm shaft fitted with the proper form of braking apparatus for use in stopping.

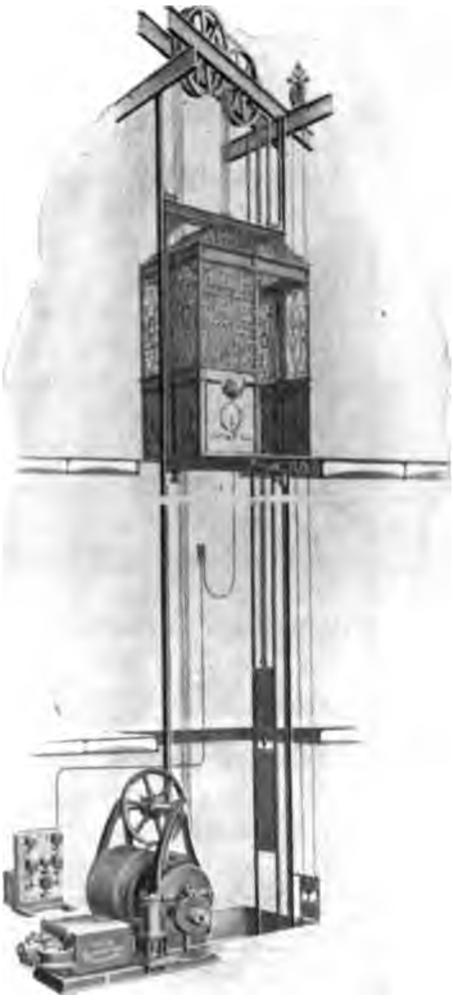
Fig. 11. Electric Elevator.

The motor used for operating an elevator has to differ somewhat from one used in driving ordinary machinery, in that it has to start up from a state of rest with the load on it, and it is a well-known fact that ordinary shunt-wound motors are very weak at starting, hence a modification became necessary. This was discovered very early in the introduction of the electric elevator.

To overcome this difficulty a very strong series field winding is used, and this is usually arranged in two or three sections, and it should furnish fully 30 or 40 per cent of the field excitation. The shunt winding is made proportional to the entire strength of the motor, and when the motor is started, both series and shunt field windings are actuated, and as fast as the motor picks up strength of speed, one section after another of the series winding is cut out, leaving the motor entirely on the shunt winding when it has attained normal speed. By this means a regular speed under any load is obtained, the series winding being used simply to give the necessary torque for starting.

The reason the series winding is cut out when the motor attains normal speed is that if left in action the speed of the motor would vary with the load, and this would be more noticeable during a descent of the load than when lifting, for it would accelerate the descent at a rate that would be constantly increasing until the end of the run. By cutting out the series winding and allowing the motor to run on the shunt only, this is avoided. These conditions are brought about by means of the controller.

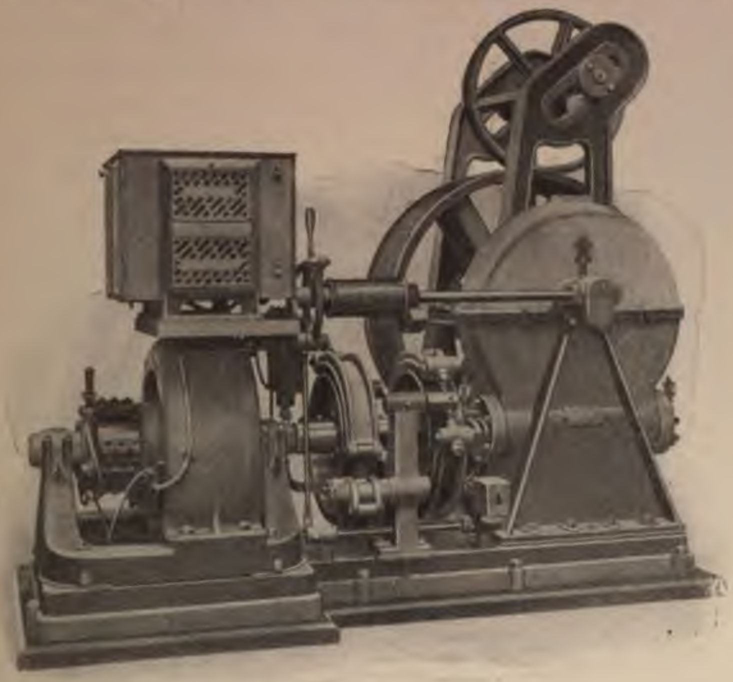

Fig. 12. Direct Connected Electric Winding Engine.

The offices of the controller are varied. It has first to turn the current into the motor through a certain amount of resistance; second, to gradually cut this out in steps as the motor increases in speed. At the same time it must gradually cut out the series winding in sections, and when the elevator is lowering, it also has to take care of the short circuiting of the armature, which will be explained later on. It consists usually of a switch for cutting out or breaking the circuit and for closing it, making suitable connections to the armature leads to cause the motor to run in the direction required. This switch is so arranged that when the circuit is closed, it releases an arm or a cross-head that drops by gravity and thereby cuts out the resistance in steps, doing it by moving the contact piece over a number of plates; the speed of its descent is governed by the escape of air from a dashpot. In some cases, instead of releasing the arm described above, it actuates a solenoid which lifts the arm or cross-head, its speed being governed in the same manner by the use of a dashpot. The breaking of the motor and solenoid circuit is done simultaneously just

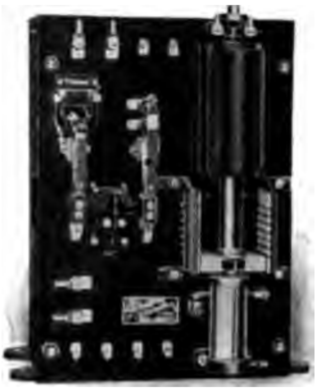

Fig. 13. Controller for Mechanial Operation.

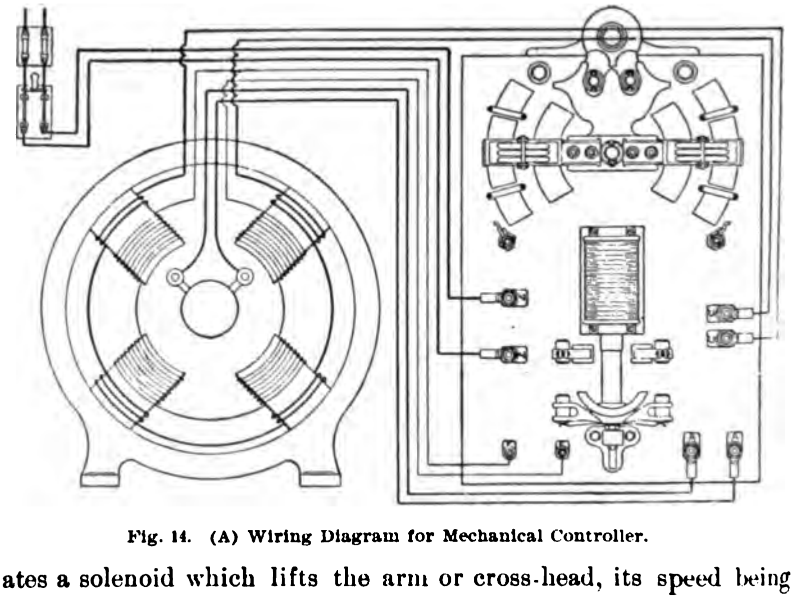

Fig. 14. (A) Wiring Diagram for Mechanical Controller.

prior to the stopping of the elevator, and where the speed of the elevator, or the weight of the loads it carries make it desirable, the controller is so constructed that when the line circuit is broken for stopping, while the elevator is lowering, it cuts in a certain amount of resistance with the armature, causing the E.M.F. in the armature to pass through this resistance, thereby retarding the speed of the motor. This E. M. F. becomes weaker as the speed of the armature decreases, until it finally ceases with the motion of the motor. This method of bringing the elevator motor to a standstill is used in all standard makes of electric elevators to-day, and has been in use since about 1895. In addition to this, a mechanical brake, operated from the rock-shaft of the machine itself, and also a separate mechanical brake, operated electrically by a solenoid, are used. In the case of the latter, the solenoid is so arranged that it releases the brake when the circuit is closed.

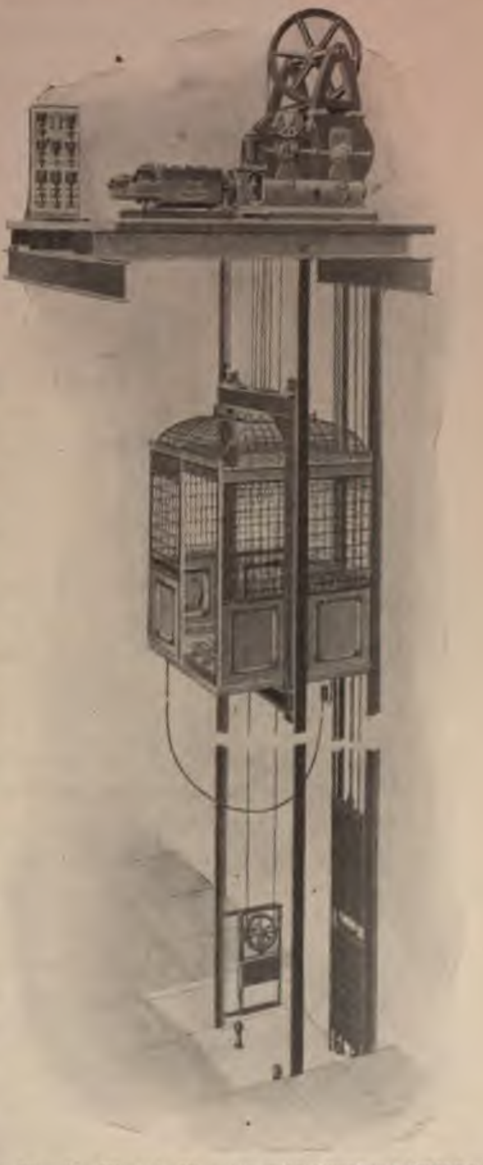

Fig. 15. Electric Elevator with Overhead Driving Mechanism.

may be, is governed by the use of a dashpot. The earlier forms of dashpots were filled with a light oil which would flow freely, and the movement of the plunger in the dashpot caused the oil to flow from one end of the cylinder to the other, through a very small opening, which was adjustable as to size. The time in which the arm or cross head passed over the cross head plates was thus regulated, but it was found that the oil was affected by temperature, very cold weather making it sluggish and thick, and the action of the arm or cross head correspondingly slow. Sometimes where the oil was of a volatile nature, considerable waste would occur from this and other causes, and then upon closing the circuit the plunger would move very rapidly until it struck the oil and was brought up with quite a shock, and resistance was cut out quickly for two or three steps. This had a bad effect. Sometimes too, the attendant would neglect to replenish the dashpot at all and it would become entirely empty; then the resistance would be cut out so suddenly as to endanger the safety of the motor. To remedy this a dashpot of somewhat larger diameter was used, having a nicely fitting piston, and the air in the dashpot was imprisoned, being allowed to escape through a minute hole at the top or bottom, according to the way the dashpot was placed. The opening being adjustable by means of a screw, the arm or cross head could be made to pass over the contact pieces at any speed desired, the usual time allowed from closing the circuit to attaining full speed being from four to five seconds.

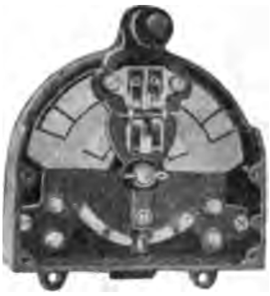
Fig. 18. Electric Operating Switch for Car.

With elevators running at a high rate of speed, however, say 300 feet per minute or more, this method of operation was not as perfect as could be desired; hence, there was devised what is called the electric control. This consists of a small switch located in the cab. From it wires are run in the form of the flexible cable to a point midway of the run of elevator, where the end of the cable is attached to the wall of the shaft, and from that point wires are run to the controller. This cable has to convey but a very small amount of current, simply sufficient to actuate one or more solenoids on the controller. These solenoids operate the switches which make and break the circuit in either direction. The throwing of this switch in the cab to the upright or central position, breaks the circuit always, and moving it either to the right hand or left will close the appropriate switch on the controller to run in the direction desired. This is done by actuating a solenoid on the controller, as before stated, which closes the switch to run the motor in the direction desired. The cable attached to this switch has to have at least three wires, one for the line, and the other two for their respective solenoids, but usually the cables are put in with a number of wires, so that if anything happens to any one of those in use, one of the dead wires can immediately be connected, and thus the necessity for replacing the entire cable is obviated.

Controllers of this description operate in various ways; in some, as soon as the line circuit is closed, a solenoid is actuated, which cuts out the resistance in the same manner as described as being used for the lever or hand-cable control. Another form of controller does it in a different manner, which will be described.

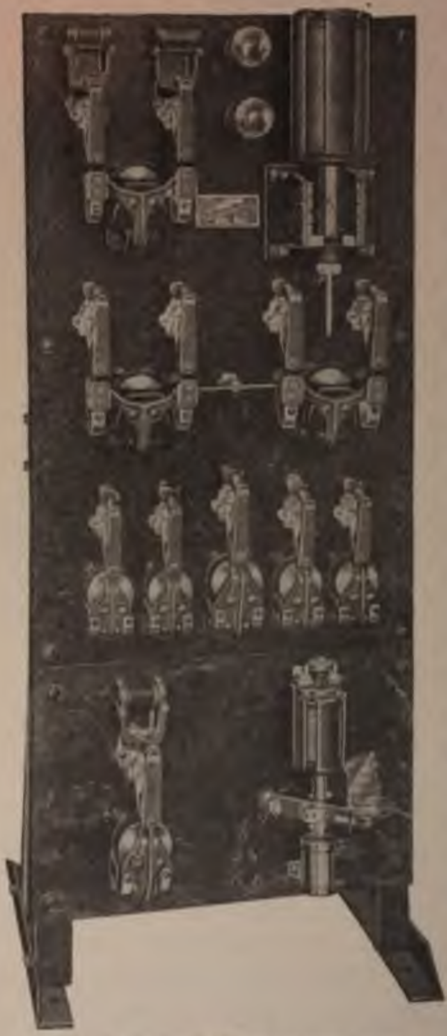

Fig. 19. Electrically Operated Controller.

The armature is connected with a number of solenoids, each connected with a separate step of the resistance, and so arranged that they require varying amounts of current to actuate them, and the E.M.F. in the armature actuates these solenoids in rotation, the motor being started up at first and running slowly, the E.M.F. in the armature is weak and actuates only the first solenoid, which then cuts out the first step of the resistance. As the speed increases, the E.M.F. becomes stronger and successively cuts, out through the other solenoids, all the resistances as the motor attains full speed. When the circuit is open for stopping the elevator, these solenoids all drop back to their original position and are ready for the next start, and they are used to cut out the resistances in either direction of the motor.

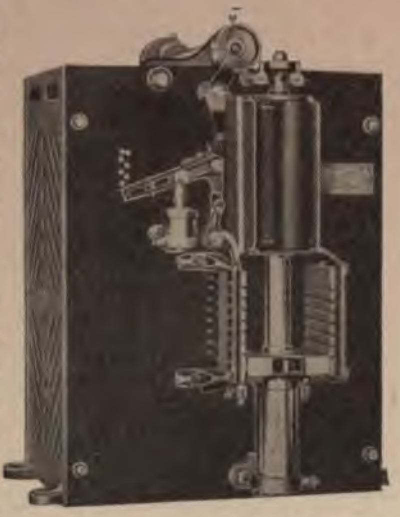
Fig. 20. Mechanical Controller, Variable Speed.

The E.M.F., as before stated, is frequently used as a means of retarding the motion of the elevator when a stop is desired, the most effective method being to introduce a set of resistances in the controller specially designed for the purpose. It is arranged on some elevators so that the E.M.F. actuates a solenoid which applies the brake, the latter being held off by a strong spiral spring. When the circuit is broken, the same movement that opens the switch, connects the armature with this solenoid, and if the elevator is running very fast, the E.M.F. being strong, applies the brake very hard. As the current in the armature, owing to the slowing down of the motor on the application of the brake, becomes weaker, the pressure on the brake becomes less, until finally it ceases entirely, and at this point the other mechanical brake operated by a solenoid, whose office is only to release it, is applied permanently by mechanical means. With this arrangement, one solenoid slows the motor and brings it to a stop, and having attained that point, the other solenoid releases its hold on the brake and allows the spring to apply it.

This latter arrangement, however, of using the E.M.F. to apply the brake, is simply a roundabout way of reaching the result—partly by mechanical and partly by electrical means—and is not really necessary; the short circuiting of the armature through resistances in the controller is all that can be desired.

In many elevators where a variable speed is desired, connection is made between the armature and a solenoid connected to a switch which is kept closed except when the solenoid is actuated. This switch closes a circuit between the shunt field coils and a bank of resistances in the controller, specially designed for the purpose, and has the effect of weakening the fields. This causes the motor to run at a greater than its normal speed, so that with a light load where the E.M.F. in the armature is not great, the elevator will always start up and run much faster than when a full load, or one nearly approaching it, is in the cage; or when the greater load has to be lifted, the E.M.F. in the armature becomes strong enough to actuate the solenoid, which opens the switch, thereby cutting out the resistance in the fields and leaving them stronger, and the speed of the motor immediately becomes slower. This is a very

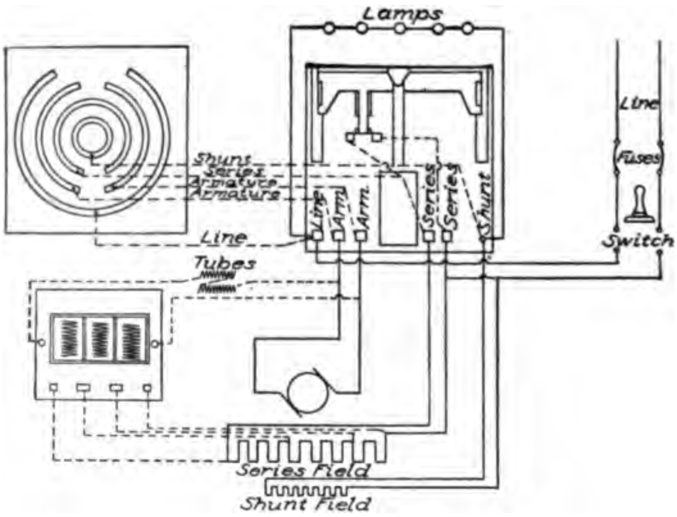

Fig. 21. (C) Wiring Diagram for Mechanical Controller.

nice device and does its work automatically and is quite reliable.

The idea of weakening or strengthening the fields of a motor to gain or lessen speed is almost as old as the first electric elevators, but where current is taken from a public supply, or where only one elevator is used, it is usually not practicable to deviate from the methods above described. The ideal electric elevator, however, is one where a separate dynamo is used for supplying the fields and one for the armature. A field regulator connected with the dynamo supplying the fields can be placed in the cab, by means of which the operator can weaken or strengthen the fields of the dynamo supplying the current to the fields of the armature driving the motor. By this means a great variation in speed may be had. But while fairly economical in its operation, it is a plant that is expensive to install, and though it has been done in a few instances, there are not many of this type of elevator in existence.

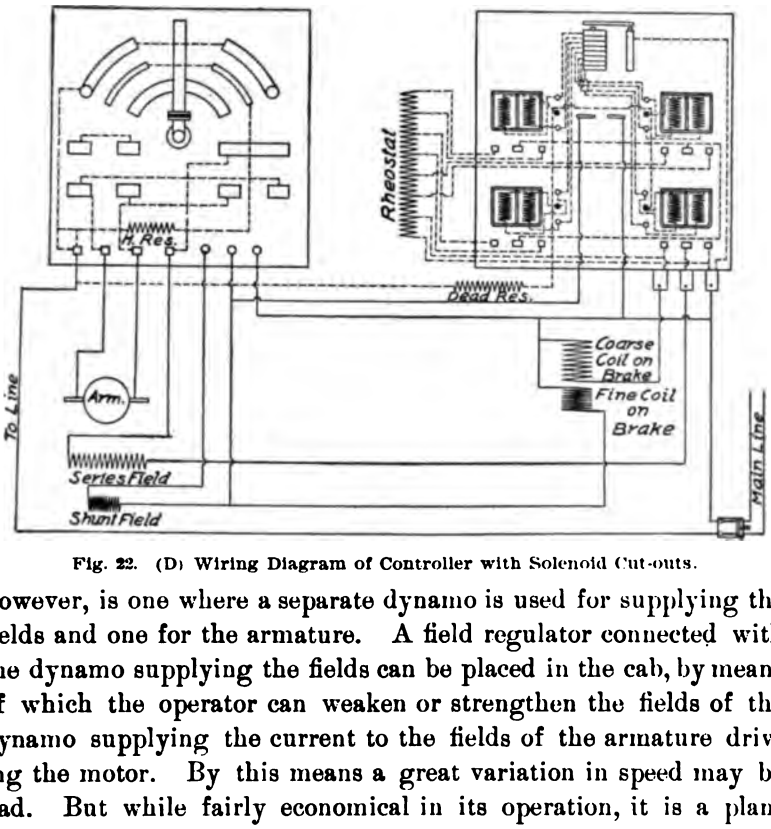

Fig. 22. (D) Wiring Diagram of Controller with Solenoid Cut-outs.

ELECTRIC LIMIT SWITCHES

It was found in operating electric elevators that more space was needed between the cab and the overhead sheaves at the upper part of the run, and that a deeper pit was also required at the bottom of the run on account of the occasional pitch of the brake.

For frequently, although the mechanical, automatic or limit stop on the machine would break the circuit and apply the brake near the end of the trip, there were cases—for instance when the empty cage was required to ascend at full speed and the brake had become slightly worn and did not grip as firmly as usual—that the cage would go beyond the landing, and the additional space mentioned above was required to prevent a collision. This also happened sometimes at the lower end of the run when an extra heavy load was descending. A lack of care on the part of the operator in breaking the circuit in sufficient time, or the causes just mentioned, would cause the cage to run down to the bottom and bump. To avoid this, as an extra measure of safety, switches are sometimes placed at the extreme limit of the run, the line wire being carried up the hatchway through the switch and returned.

These switches are opened by the car automatically if it should pass a certain point, and the opening of this switch breaks the circuit and at the same time applies an extra strong emergency brake. The switches are operated by means of cams attached to the cage.

MISCELLANEOUS ELECTRIC ELEVATORS

There are one or two other types of elevators that have been more experimental than practical in their nature, which will be mentioned here. One of them, the Pratt-Sprague, consists of a hand screw running horizontally in bearings at either end, which is driven directly by a motor placed at one end. The screw runs in a nut having a cross head, which travels on guides horizontally, the same as the cross head of a horizontal hydraulic, and is supplied with sheaves on either end. The construction of the machine is such that a double set of traveling sheaves and also fixed sheaves is necessary. The cables are rolled over these sheaves similar to the method described for the horizontal hydraulic, and the motor, of course, is reversible.

One of the principal features of this type of machine was the construction of the nut which traveled on this large screw. It was supplied with steel balls on the pull side of the screw, and they ran close together in single file through a channel, which carried them around through the threads of the nut and caused them to return to the other end of the same after they had passed through. Of course, there had to be so many of them that they completely filled the channel from one end to the other, and it was thought that their use would reduce the friction to a minimum. It was found, however, in practice that they would get flat spots on them and cease revolving, and where they did this they would cut grooves or scores in the thread of the screw, which latter was a serious matter. They are very prone also to become deranged, and their operation was not as economical as had been anticipated.

Very few of these elevators are in use at the present time. The controlling device, however, was quite novel and the operation of the cage very agreeable and pleasant. The control of the motor driving this screw was effected by means of a small pilot motor operated in turn by means of push buttons in the cage.

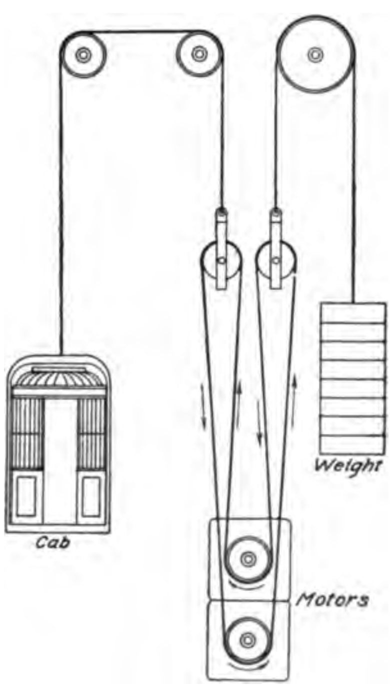

Fig. 23. Diagram of Fraser Elevator.

Another type of elevator was that devised by Mr. Fraser, of California, the driving mechanism of which consisted of two motors set one above the other. They were necessarily slow speed motors, and each one had upon the armature shaft sheaves of about 20 inches diameter. The motors themselves ran at a speed of about 420 r.p.m., and the cables were so arranged as to form a double bight or loop below, in each of which one of these pulleys on the armature shaft ran as shown in the accompanying illustration. The upper ropes of the cables had sheaves carrying them and running in a frame, to one of which was attached the car cable, and to the other the counterpoise cables. These motors ran in opposite directions, and in the cab were placed rheostats for weakening or strengthening the fields. By this means the speeds of the motors could be varied. By reference to the diagram illustrating this description, it can readily be seen that when both motors were running at the same speed, no motion of the car was obtained, but by varying the speed of either motor the car would run at a speed equal to half the difference of the two motors. No reversing apparatus was needed with these motors; they ran continuously in one direction, the motion of the car being gotten entirely by the change in speed, and the most desirable stops and starts were obtained. But the machine was very severe on the cables, so destructive in fact that they had to be renewed frequently; and taking it altogether, it was not found as desirable a machine as had been anticipated, either from the point of economy or maintenance, but results in operation were all that could be desired, including the speed attained and smoothness of stops and starts.

ELEVATOR ACCESSORIES

An elevator is really a vertical railway, but differs from one running on horizontal rails in that it does not use wheels, but slides on its track, and in order to avoid friction as much as possible, the cage should be hung centrally. The rails used for the cage to travel on are, in the more common types, usually of wood, hard maple being the material mostly adopted, and it is kept constantly lubricated with some form of grease. The guide ways after some weeks' use become rough and dry from various causes, principally from the rubbing off or evaporation of some of the component parts of the grease, and also from the accumulation of dust, which sticks readily to the lubricant. They then have to be cleaned off and relubricated, the object being of course to keep them as smooth and free from friction as possible.

Great care has to be taken when installing them to have them in perfect alignment and the joints very even; and maple, being a wood that is prone to warp, has to be put on in short pieces, the usual lengths being about four feet. The ends of these guides are tongued and grooved to fit into one another, and where the guide posts, to which they are attached, are made of wood, they are fastened thereto by means of appropriate lag screws, the ends of which are recessed into the face of the guides. The shoes on the cage which run on these guides are usually machined to fit, and are made as smooth as possible at their faces of contact.

The device generally used for stopping the cage in case of a sudden descent, caused either by the breakage of the cables to which the car is suspended or by the derangement of any part of the machinery, is a pair of dogs, one placed in each guide-shoe beneath the car on opposite sides. These dogs are in the form of an eccentric, the outer face of which is supplied with coarse teeth, which, when the dog is revolved on its axis, come in contact with the guide strips; and as these teeth enter it, the descent of the car causes a further partial revolution of the dogs, so that the guides become tighter and tighter as the car descends, and bring it to a stop. This operation takes much less time to occur than it does to describe it here, the fact being that after the dogs begin to catch, the car descends but a very few inches before it is brought to a dead stop.

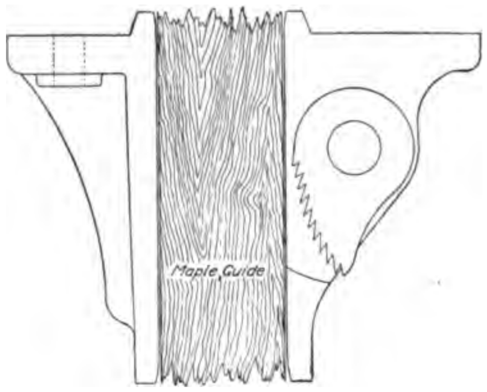

Fig. 24. Eccentric Safety Dog.

These dogs were originally used in connection with a spring for throwing them; hence when they acted at all they acted very quickly and before the platform had gained much headway, and while this was quite satisfactory in a slow running elevator, it was found to be quite objectionable with elevators of high speed—the sudden stopping producing a severe shock to the occupants of the cage—and moreover there were many cases where the elevator would descend rapidly, and the dogs failed to act, because they depended on the severing of the hoist cables for their action. They were operated by a spring which, being held in tension by the weight of the cage on the hoisting cable, would never act while that tension existed. Hence, if the cables were to break at or near the drum of the machine—the machine being located in the basement—these cables had to pass from the drum up and over sheaves at the top of the hatchway and it would require considerable power to drag them over these sheaves. This would be sufficient in itself to hold the spring out of action.

With the introduction of the safety governor, however, this trouble disappeared. The governor is a revolving sheave having within its rim dogs or arms set upon pivots and held in place by means of strong springs, either spiral or flat. These springs are so adjusted that the normal speed of the elevator does not affect either them or the dogs, but should the speed of the elevator exceed the normal by about 25 per cent, the centrifugal force exerted by these dogs, which are weighted somewhat, will overcome the tension of the springs, and they will fly out beyond the rim of the sheave, catching on a stand in which the sheave runs and stopping its revolutions entirely.

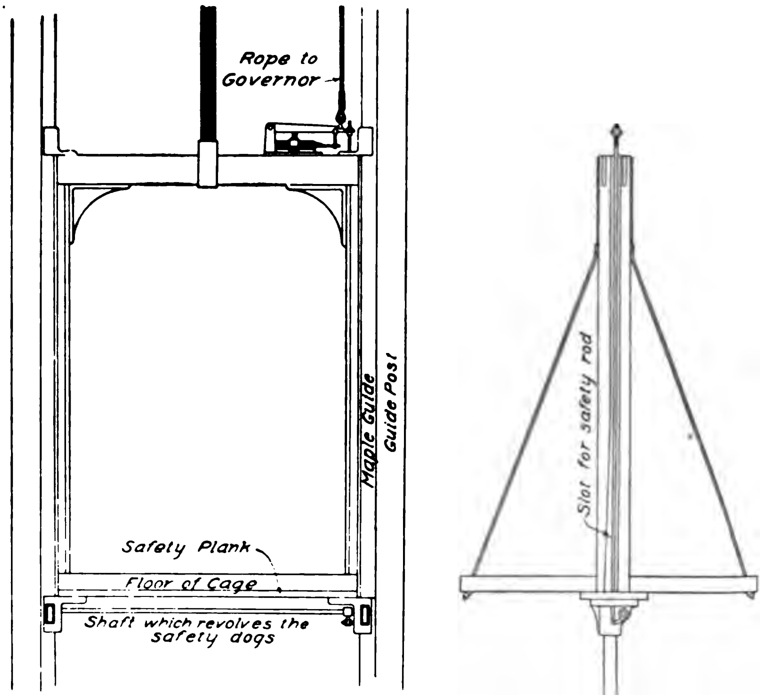

Fig. 25. Arrangement for Throwing Safety Dogs.

Now this sheave has a V-shaped groove in which runs a manila rope about $\frac{3}{4}$ inch in diameter. One end of this rope is made fast to a lever on the top of the cage, which operates the safety dogs, the other end is carried down the hatchway and around another sheave at the bottom and back again up to the cage, where it is attached at some convenient point, usually to an arm placed on the stile for that purpose. This sheave, which runs in the bight of the governor rope, is in a frame, which runs on guides and has a moderately heavy weight attached below it which serves the double purpose of keeping the governor rope taut and of taking up or compensating for the stretch of the rope. It also gives the necessary tension for driving the governor, and when the sheave and its revolutions throws out the dogs and stops itself, as before described, the V groove in the sheave grips the governor rope tightly and thereby pulls on the safety lever on the cage and throws in the safety dogs. It can be readily seen that with an appliance of this kind, the cage would have to descend quite a

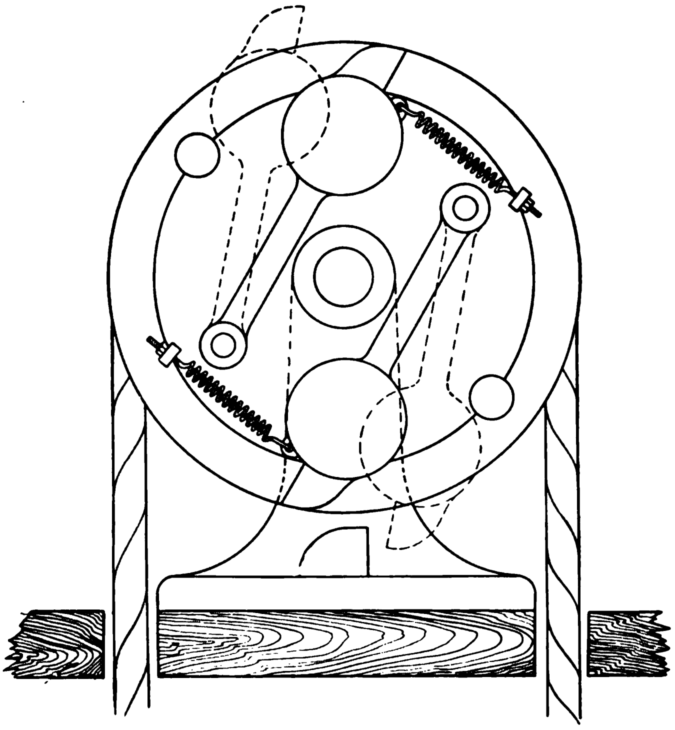

Fig. 26. Diagram of Safety Governor.

before described, which were not applicable to this form of guide, hence a new device had to be introduced. This was in the form of a powerful pair of nippers placed below the car, one on each side. The inner ends of these nippers on being forced outward, caused the jaws of same to grip the steel guides with tremendous force, but the means of applying them being gradual they did not stop the cage suddenly but allowed it to slide several feet, bringing it gradually to a stand.

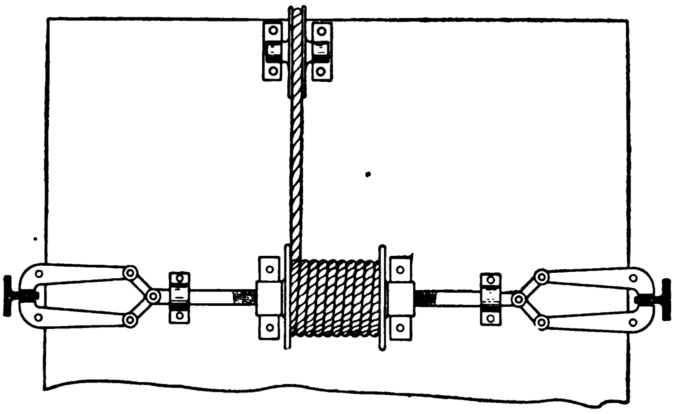

Fig. 27. Safeties for Steel Guides.

The form of governor used to actuate these safeties is similar to that described above. The pulling of the governor rope causes the release of a very powerful coil spring under the car, which forces the dogs into action. There are several forms of this device, none of them differing materially, except in the method of applying the power to grip the guides, one or two of them dispensing with the coil spring, before mentioned, and using a powerful screw and knee joint. The screw is operated by the end of the governor rope, which is coiled several times around a spool or barrel on the body of the screw. The governor rope is gripped by the governor, and the descent of the car uncoils the governor rope off the spool, which is made to revolve, and, being attached to the screw, causes it to revolve. This action causes the knee joints to force the long end of the nippers apart, the short ends gripping the guides powerfully.

Another point in which the elevator differs from the horizontal railway is that in moving a load on an elevator the force of gravity has to be overcome as well as that of inertia. Hence, it is found to be economical to counterbalance the cage, and for that reason slides very similar to those on which the cage travels, but lighter in construction, have to be provided, in which a counterpoise weight travels. Sometimes more than one of these counterbalance weights are used, in some cases running in separate slides, in others, varying with the conditions, with each weight having a slide to itself.

When a counterbalance weight is used, which is attached directly to the cage, it can never be as heavy as the empty cage by several hundred pounds, depending largely upon the height of the building and the number of cables attached, for when the cage is at the top of the run, these cables hang over on the opposite side of the sheaves and have the effect of further counterbalancing the cage. The weight of the cage itself must therefore be greater than the combined weight of these cables and the counterbalance weight, otherwise, the cage would not descend when empty. When it becomes necessary to have the counterbalance weight fully as heavy as the empty cage, or, as occurs in many instances, it is required to be greater than the cage, this counterbalance weight has to be attached by means of cables running over sheaves at the top of hatchway to the opposite or back side of the hoisting drum. Where a cage is large and consequently quite heavy, the attaching of a counterpoise to the cage itself, as well as to the rear side of the hoisting drums, is done as a means of relieving the hoisting cables of a part of the weight they have to carry, and this adds to their durability and safety.

In the case of the electric elevator the over-counterbalancing of the cage is found to be quite economical in this way. An estimate is made of the average load which the elevator has to lift in its daily service, and it is over-counterbalanced to about this amount, the result being that, with the average load, the only power to be exerted in moving it will be that necessary on account of the friction of the machinery. For instance, it may be estimated that the average load of the elevator will be 500 or 600 pounds, although it is built to lift say 2,000 pounds. If it is overweighted this amount, it will be on a balance with the average load, and the amount of power required to move it will be a minimum.

This arrangement is found to give very good results as to economy and operation, but of course in order to get the very best results the cage should be built as light as possible commensurate with the requisite strength and stability; for if the cage is made unnecessarily heavy and it has to be counterbalanced equivalent to its weight, there is that much heavier body of material to start and stop each time the elevator is operated, and there is that much greater inertia to overcome, which consumes power. The necessity, therefore, of building everything as light as possible will be readily seen.

Where two counterbalance weights are used running in one slide, it should be an invariable rule to place the heavier weight, which is always that one attached to the rear side of hoisting drum, below the one attached directly to the cage, for there is a liability at times of counterbalance weight cables breaking, the same as there is with hoisting cables. Should this occur with the drum or heavier weight above the cage weight, the consequences would be disastrous, for combined they would weigh considerably more than the cage, and in falling would rush it upwards to the top of the hatchway at a great speed, provided of course that the cables by which the car weight was attached did not give way. Where the cables of the lowering weight pass the upper weight, the latter is usually slotted throughout its whole length to allow their passage.

The best form of counterbalance weights used at the present time in elevators is made in sections so as to be readily changed or adjusted when desired. They consist of a head and bottom weight, which are usually provided with suitable guide shoes to run on the slides, and between them are shorter weights, which do not touch the guide, and which are called subweights. The whole number of weights are held together by means of strong iron rods with double nuts at either end. These pass through holes cast in the upper and lower sections of the weight, and the intermediate or subweights are held in position on these rods by means of grooves in their ends, which fit over the rods, the whole being clamped together firmly by means of the nuts just mentioned.

Sometimes, where the counterbalance weight is necessarily very long, a middle weight with guides on it is inserted, through which the rods holding in the subweights pass, thus giving it greater rigidity and safety.

A very important part of the elevator is the overhead sheaves and bearings. In the earlier forms of elevators, these bearings were set on wooden beams overhead, passing across the hatchway in the proper direction to let the cables drop where required. In later years, however, general practice seems to lean to the use of steel I-beams for this purpose, and they are certainly much safer in case of a fire occurring in the building. It frequently happens in case of a fire that the elevator is one of the principal means for getting people out of the building, and where these beams are of steel there is no doubt as to their greater safety under such conditions. The sheaves should always be as large as can possibly be used under the circumstances,—never less in diameter than the drum around which the cables wind—and the rule usually adopted is that the sheave should be at least 40 times the diameter of the cable which is to run over it, and as much larger than that as the conditions will permit. It is also very important that the score of these sheaves should fit the cable very well, otherwise, with heavy loads the latter becomes distorted, and even under the best conditions the wear of the cable will be rapid unless lubricated. For this purpose, there is nothing better than raw linseed oil applied with a brush, and it is very much improved in usefulness if a small quantity of the finer quality of plumbago be mixed with it. This material when unrefined is full of grit, and is put on the market in this condition for use as facing for moldings in foundries. It is very essential that this kind be not used, for the presence of the grit will have exactly the oppposite effect to that intended. After the plumbago has been carefully freed of all the grit it contains, it is a very good lubricant and in this condition it is very serviceable, both for the purpose just described and, in connection with grease, for the slides.

CABLES

Should the wires of the cables used in hoisting be run perfectly parallel to one another, they would not only last longer but they could be subjected with safety to a much greater strain, but that is found to be impracticable with running ropes, hence they have to be twisted, first in strands of 19 wires each, then six of these strands are twisted together around a center or heart made of hemp. The object of this arrangement is that in working over the sheaves the wires may rub on something softer than themselves and not abraid, for the parts of a hoisting cable when in use undergo many changes in position. For instance, when passing up the hatchway, the parts remain normal or as they were when made up, but when they come to the sheave the strands necessarily change positions slightly, being bent in a circle, and after passing over the sheave and down on the other side they change again to nearly the original position. As they are twisted around one another, different parts of the same cable change their relative positions quite frequently, for their very shape—being spirally wound around one another—causes them to roll slightly in the grooves of the sheave, and they do not always fall into exactly the same position when they return. Hence, the absolute necessity for some sort of lubrication. This change of position or twisting of the cables has made it advisable in cases where a large number of cables are used together (say for instance four or six cables running over one sheave) to use them alternately of right and left hand lay, the meaning of which is that some cables are twisted right-handed and others left-handed, and by using them alternately in this way they serve to correct the action of each other and prevent many minor troubles that will occur when laid up alike.

The scope of this article will not permit going into details relative to the proper fastening of the cables, which is a very important feature, but which is really in the hands of the elevator constructor, and with which the attendant has little to do.

The journals of the gudgeons or shafts upon which the sheaves revolve should always be of soft shrunk steel and of ample diameter, and the boxes in which they run should be lined with a very good quality of babbitt, and should be provided with good lubricating facilities. They are parts of the elevator that are neglected perhaps more than any other. Being at the highest point and out of the way, they are very seldom noticed, but at the same time too much emphasis cannot be placed upon the absolute necessity for properly attending to this important feature of the machine.

The operating cable, owing to the impossibility of following the rule laid down for the hoist cables regarding the diameters of sheaves, is usual to make of a much finer wire, and the number of wires to a strand is also greater. It is usually that kind of wire rope which is termed tiller rope, and is soft and flexible. The diameter is almost invariably ½ inch, except in cases where the lever device is used, when the necessity for a rope of that size does not exist. The ½-inch diameter is used principally because it is convenient for the hand, and it is seldom that a larger sheave than 12 inches is found practicable, but in any case, whether for hand cables or hoisting cables, iron ropes should always be used. It is true that a steel rope has a greater tensile strength, but the bending over the sheaves causes it to crystallize much more rapidly than an iron rope does, and it will consequently commence to crack sooner. The very best iron for this purpose is either Swedish or charcoal iron, which are very nearly pure, exceedingly ductile, and will stand the bending and straightening for a much greater length of time than a steel rope.

Wire cables have, in some instances, been known to run without fracture for eight, ten, and even twelve years, but there are very few in constant use that last more than three or four years. Some do not last longer than two years where subjected to constant and severe service, and in any case they should, on general principles, even if showing no outward signs of deterioration, be changed for new ones at the end of five years, under the most favorable circumstances. Cracking occurs very gradually and can readily be detected long before it actually occurs by the exterior appearance of the rope, but there are many cases where ropes crack inside before they do on the outside, and this can only be discovered by getting the rope entirely slack and slightly untwisting it so that an examination of the interior can be made. Holding one's hand gently on the rope while it is running will frequently detect a cracked wire if it be on the outside, but an examination of this kind must be carefully made to be of any service.

In regard to sheaves, sometimes an arm will crack through an undue shrinkage strain brought about possibly in some cases by disproportion in the design, or by unequal cooling in the foundry. In such cases the crack usually opens quite wide, but where it occurs from undue shock or jar, the fracture may occur and remain closed, so that it is not detected. Still the sheave is unsafe. Usually this can be perceived by care on the part of those in charge, for when the arm containing the fracture is in such a position that it is not subjected to the strain of the cable running over it, the crack, however minute, will open slightly, and it is liable to absorb or take in a minute portion of the oil which is generally on the sheave and which runs down from the journal boxes. This arm when it comes around to that point where it is subjected to compressive strain will force the oil out of the fracture in the form of a small line projecting above the surface of the sheave. It requires a sharp eye to detect this, but it can be seen with care, and many a possible accident has been avoided by the acuteness of the attendant in this respect. It is here mentioned for the benefit of those readers who may be in charge of elevators.

AIR CUSHIONS

About 1878 Mr. Gray, of Cincinnati, conceived the idea of an air cushion as an extra means of safety for elevators, and obtained the first patent for a device of this kind. The air cushion consists of an extension of the hatchway below the lower landing, and is in the form of a strongly enclosed air-tight chamber open only into the hatchway above. The guide posts are run down into this hatchway and the cage is made to fit it rather closely. This is usually done by fastening strips of thick rubber or leather below the floor of the cage, and allowing them to project to within about ½ inch of the sides of the air cushion. Now in case the cage should break loose from the cables, it will descend until, having entered this chamber a certain distance, the air contained within the chamber is compressed sufficiently to resist the further descent of the cage. At this point it begins to escape through the margin left all around the sides and the speed of the cage's descent is retarded until it sinks gradually to the bottom of the chamber without shock or jar.

The margin all around the cage for the escaping of air is a very essential feature to the success of this device. Many errors were made in some of the earlier forms of this device, owing to this feature not being well understood, for it is quite possible, where the air is confined too closely, to stop the cage violently; in fact, this will be the effect if the air is not allowed to escape. On the other hand, if too wide a margin is left, the effect desired will not result. Great care has to be exercised to have the chamber forming the air cushion air tight, strong enough to resist the strains that will be brought to bear upon it, deep enough to enable the car to come to a stop gradually, and to have the air space around the car just right to allow the air to escape in sufficient quantity to prevent a shock, and at the same time not fast enough to allow the car to drop too quickly after it enters.

The usual depth of the air cushion is about 8 or 9 feet and the space or margin left between the cage and sides of air cushion is from ⅜ to ½ inch. Some modifications are usually made after the work is finished by dropping the cage from a moderate height and noting results, before allowing it to drop the full extent of the run. This is an experiment that should not be performed by inexperienced persons, for accidents have frequently happened even to men thoroughly experienced in the business.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for College, Civil Service, or Engineer's License. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

HEAT.

EXERCISE I.

1. What is the difference between heat and temperature?

2. How are the freezing and boiling points of a thermometer determined?

3. To what temperature F does —10° C correspond?

4. To what temperature C does — 20° F correspond?

5. What is the temperature of steam when the barometer stands at 30.05 inches?

6. What is the absolute zero of temperature?

EXERCISE II.

1. Give an example of linear expansion from your own observation.

2. A silver dollar is nicely fitted into an iron ring. If both are heated, will the coin fit more or less tightly?

3. A steel rail is 30 feet long at 20° C. How long is it at 0° C?

4. A surveyor's steel tape 100 feet long is correct at 60° F. How much in error is it at 86° F?

5. One end of every long iron bridge rests on rollers. Why is this?

6. 700 cubic feet of air at 20° C are heated to 50° C. Find the increase in volume.

EXERCISE III.

1. What is the difference between evaporation and ebullition?

2. For what reason is it not difficult to boil water on top of a high mountain?

3. If a plug of tin were screwed into a steam boiler, would it remain in its position if the steam pressure were raised to 100 lbs. per square inch?

4. Upon what does the process of distillation depend? Why is the cooling water fed in at the bottom rather than at the top?

5. What is a British thermal unit?

6. What is the maximum possible efficiency of a steam engine taking steam at 185.3 pressure (gage) and exhausting at 15 pounds absolute pressure?

EXERCISE IV.

1. What is meant by the latent heat of fusion? Does the temperature of a substance change during solidification?

2. How many pounds of water at 60° C will be required to melt ten pounds of ice at —5° C?

3. How many pounds of steam at 212° F will just melt 100 pounds of ice at 32° F?

4. How many pounds of steam at atmospheric pressure will raise 2,000 pounds of water from 40° F to 50° F?

5. Define specific heat in your own words.

6. What is superheated steam?

EXERCISE V.

1. Is there any thermal advantage in making a boiler of copper rather than of iron?

2. What is the difference between conduction and convection?

3. Suppose you wished to heat a liquid that contracted considerably on heating. Would you apply the heat at bottom or at top?

4. An iron ball is heated, but not to redness. Does it emit any energy other than by heating the air surrounding it?

5. Give an illustration from your own observation of the conversion of mechanical energy into heat.

6. How many foot-pounds of work can be obtained from a pound of coal having 14,000 B. T. U.? Assume 7 per cent to be used.

EXERCISE VI.

1 What is the first law of thermodynamics? How many foot-pounds are there in one B. T. U.?

2. Does heat tend to pass from a high temperature to a low, or the reverse? Give an example from your own observation.

3. Could a steam engine work if the temperature of the boiler were no higher than that of the exhaust pipe?

4. For what reason is brine used to surround the vaporizing coils of an ice-machine?

5. How does the liquid-air apparatus utilize the cold produced by expansion?

6. Explain the difference between the absorption and compression systems of refrigeration.

REVIEW QUESTIONS

ON THE SUBJECT OF

CHEMISTRY.

1. What do you understand by an atom? A molecule?

2. What is the standard of molecular weight?

3. Name all the elements you have ever seen.

4. Without looking at the table on page 7, write the symbols of iron, calcium, sodium, lead, carbon, sulphur, aluminum, silver, oxygen, chlorine, hydrogen, potassium, nitrogen, zinc and magnesium.

5. What is the law of conservation of matter?

6. Write the formula for water, common salt, sulphuric acid, sodium carbonate, carbon dioxide, lime, ammonium hydrate, hydrochloric acid, nitric acid, and sulphur.

7. Write the equation of sulphuric acid on lime (calcium oxide).

8. What is the atomic weight of oxygen, carbon, nitrogen, iron, calcium?

9. Why is distilled water pure?

10. What is "hard" water? What is the cause of temporary hardness? What is the cause of permanent hardness?

11. Give the molecular weight of common salt, $NaCl$; of sodium carbonate, Na_2CO_3; of sulphuric acid, H_2SO_4; of ammonium sulphate, $(NH_4)_2SO_4$.

12. Name the two principal processes for making sodium carbonate.

13. What are the products of combustion when coal is burned in plenty of air?

14. What happens in a chemical change?

15. State briefly the properties and characteristics of oxygen.

16. How much anhydrous sodium carbonate, Na_2CO_3, is there in ten pounds of crystallized sodium carbonate : $Na_2CO_3 \cdot 10\,H_2O$?

17. What percentage of lead is there in litharge, lead oxide, PbO ?

18. How many pounds of air are theoretically necessary to completely burn 200 pounds of coal that contains 82 per cent. of carbon and 8 per cent. of hydrogen ? Ans. 2,459 pounds.

19. What is the valence of the metals in the following, CuO, K_2O, and $AgCl$?

20. How is water-gas made ? (b) Why is it more dangerous to life than ordinary coal gas ?

21. Is air a chemical compound or a mechanical mixture ? How do you know ?

22. Explain with reactions the combustion of coal in a stove.

23. What do you understand by valence ?

24. The water used for a boiler contains 2 pounds calcium sulphate per 1,000 gallons. How much pure sodium carbonate will be required to precipitate the calcium as carbonate, assuming the reaction

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4.$$

25. Name the most important gases found in the atmosphere.

26. Describe briefly carbon dioxide and carbon monoxide and state their chief differences.

27. Complete the following reactions:

$$?HNO_3 + Ca(OH)_2 = \, ? + H_2O$$
$$CaO + H_2O = \, ?$$
$$Na_2CO_3 + ?HCl = \, ? \; H_2O$$

28. How much sulpuric acid (100 per cent. H_2SO_4) will be required to dissolve 20 pounds of iron ?

$$Fe + H_2SO_4 = FeSO_4 + H_2$$

How much commercial sulphuric acid containing 95 per cent. H_2SO_4 would be required ?

REVIEW QUESTIONS

ON THE SUBJECT OF

CONSTRUCTION OF BOILERS.

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1. If they are near together how are two flat parallel surfaces stayed?
2. Describe a rivet.
3. Since copper is such a desirable metal for boiler work why is it not used more extensively?
4. Why is a large factor of safety used for stays?
5. State what you can (briefly) about the injuries done to plates by punching and the methods employed to overcome them.
6. Why are not welded joints used more generally?
7. In what two ways are tubes fastened to the tube sheet?
8. About what is the ratio of length to diameter of the multitubular type of boiler?
9. Explain riveting with countersunk head.
10. Is the greatest tendency to rupture along the longitudinal or the circumferential seams?
11. Why is the length of a grate limited?
12. Which is the stronger form of riveting, the lap joint or double butt joint (both with double riveting)?
13. Why are the short screw stay bolts turned smooth in the center?
14. Why are flanged joints preferable to those made with cast iron angle irons?
15. What is the water-leg?
16. For what qualities are boiler materials tested?
17. What is the principal advantage of pneumatic calking?

18. Name some of the considerations that must be kept in mind when designing a boiler?

19. If the rivet is 1 inch in diameter what would *you* make the pitch, if single riveted lap joint?

20. Upon what does the choice of type of boiler depend?

21. What is the thickness of the shell of a boiler if the diameter is 60 inches, the steam pressure 70 pounds per square inch, the joint has an efficiency of .68 and the working strength of the metal 9000 pounds per square inch? The working strength equals the breaking strength S, divided by f.

Use the formula $t = \frac{fDp}{2SE}$. Ans. $\frac{3}{8}$ inches.

22. Find the allowable pressure, if the above conditions are the same, with the exception of t, which is $\frac{1}{2}$ inch.

Ans. 102 pounds per square inch.

23. Why should calking be done carefully and with a proper shaped tool?

24. About what fraction of the volume of a multitubular boiler is the steam space?

25. If the boiler is to supply steam to a high speed engine, should the steam space be larger or smaller than if to a low speed engine?

26. Why is wrought iron preferable to cast iron for boiler shells?

27. Why is a riveted joint weaker than an uncut plate?

28. A boiler evaporates 3211 pounds of water per hour. The grate is $6\frac{1}{2}$ feet by 4 feet and the coal evaporates $9\frac{1}{2}$ pounds of water per pound. What is the rate of combustion?

Ans. 13 pounds per sq. ft. per hour.

29. What kind of joint is generally used for longitudinal seams?

30. What should be the diameter at the top of a chimney 81 feet high if 2.88 pounds of coal are burned per horse-power per hour, and the horse-power is 160?

Use formula foot page 56. Ans. 28 inches.

31. Name four general requirements that a boiler must have.

32. What are the advantages of machine riveting

REVIEW QUESTIONS

ON THE SUBJECT OF

TYPES OF BOILERS.

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1. Why are water-tube boilers lighter than those of the fire-tube type?

2. In the fire-tube boiler, are the tubes large or small for forced draft? Why?

3. Make a sketch of a multitubular boiler and locate the important parts. Show by means of arrows the path of the hot gases.

NOTE: The sketch should combine Figs. 12 and 13.

4. Name three boilers that have curved water tubes, are non-sectional, and have a steam drum of the cross type.

5. Describe briefly the Stirling boiler.

6. Classify, under the headings "sectional" and "non-sectional," all the water-tube boilers described in this Instruction Paper.

7. Trace the changes that occurred in the development of the horizontal multitubular boiler from the plain cylindrical.

8. What is the peculiarity of Beggs' Directurn Boiler?

9. What are the advantages of the double-ended return-tube boiler?

10. Trace the path of the hot gases in the Atlas boiler. For what purpose is the third drum?

11. In what way does the Niclausse boiler differ from all others here described? Trace the course of the water. Describe the construction.

12. Describe briefly the flue boilers,—Cornish, Lancashire, and Galloway. Identify each by stating the peculiarities in a few words.

13. What is a Breeches-flued boiler?

14. Sketch the longitudinal section of a single-furnace single-ended return-tube boiler and name the principal parts.

15. Is the Babcock and Wilcox a sectional boiler? In what way does it differ from the Root?

16. What is the chief peculiarity of the Harrison boiler?

17. How does the Belpaire fire-box differ from the Wootten?

18. Why are vertical fire-tube boilers not economical? Describe the fire-box construction in the Manning boiler?

19. Describe the feed water heater used with the Mosher boiler. Is this a sectional boiler?

20. What two boilers belong to the class that may be briefly described as:

Straight Vertical Water-Tubes, Single-Tube, Non-Sectional.

21. Describe the Robb–Mumford boiler. Why is the furnace flue corrugated? Why is the lower shell inclined?

22. In what ways does the Hazelton boiler differ from the Wickes?

23. Why should the boiler shown in Fig. 34 be economical and at the same time occupy but little space?

24. Name all the boilers you can think of that have the following characteristics:

Water-Tube—Non-Sectional—Straight-Tube—Water-Tubes Horizontal Or Nearly So—Steam Drum Horizontal.

25. Is the Worthington boiler sectional? What can you say regarding the extent of the furnace as compared with the tubes?

26. Discuss briefly some of the advantages claimed for water-tube boilers.

27. Why should one of the brackets supporting a multi-tubular boiler be placed on rollers?

28. In general, how are flat plates within a boiler prevented from bulging or collapsing? How are two flat or curved surfaces stayed when they are close together?

29. The Cahall boiler may be described as follows:

Water Tubes Vertical—Straight-tube—Non-Sectional.

Why cannot the Milne be placed in the same class?

30. In what boiler are small circulating tubes used for obtaining dry steam?

REVIEW QUESTIONS

ON THE SUBJECT OF

BOILER ACCESSORIES.

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1. When are check valves used? Explain the action.
2. What is the unit of boiler horse-power?
3. What devices are used to drain condensation from steam pipes?
4. What are the defects of the lever safety valve?
5. Why should the feed supply be regulated so that the water level shall be as nearly stationary as possible?
6. Describe the principle upon which the injector or inspirator works.
7. Why is it necessary to reduce the actual evaporation to an equivalent evaporation, before comparisons can be made?
8. Name some methods for preventing smoke.
9. Describe the two types of feed water heaters.
10. Of what are fusible plugs made? Where are they placed?
11. What are the requisites of a good boiler setting?
12. What portions of a boiler should be kept clean?
13. What is a good average heat value for coal?
14. In building a fire 360 pounds of wood were used. What is the coal equivalent?
15. State some reasons why the efficiency of a boiler and furnace is considerably less than 100 per cent.
16. Describe the pop safety valve.
17. What should be the diameter of a safety valve when

the boiler evaporates 1.346 pounds of water per second, if the lift is .1 of an inch and the pressure 100 pounds (absolute)?

Ans. 8 inches.

18. Describe the process of banking a fire.

19. What harm is caused by the admission of engine oil to the boiler?

20. In general, how are boiler explosions prevented?

21. What are the three kinds of firing?

22. Name and state the objects of the two kinds of boiler tests.

23. Describe the action of the down draft furnace.

24. Where is the feed water generally introduced?

25. Name some good pipe coverings.

26. Why is scale undesirable?

27. Why should the steam space never be exposed to the heat of the fire?

28. A lever safety valve is set to blow off at 65 pounds. The ball at the end weighs 110 pounds, the lever weighs 48 pounds and has its center of gravity 18 inches from the fulcrum. The valve is $4\frac{1}{2}$ inches from the fulcrum. The valve has a diameter of $4\frac{1}{2}$ inches and with the spindle weighs 14 pounds. At what distance from the fulcrum must the ball be placed?

Ans. $33\frac{7}{8}$ inches (nearly).

29. Describe in detail the methods for starting a fire in a boiler furnace, for bituminous coal.

30. Why are patches of scale more harmful than a uniform coating?

31. If you were in charge of a boiler and the gage cocks gave no indication of water, what would you do?

32. Describe briefly the two most important kinds of coal.

33. Show why it is economical to introduce the feed water at a high temperature. What per cent. is gained if the feed water enters at 200° F. instead of 60° F.? The pressure is 110 pounds (gage).

34. Describe the action and principle of the Bourdon gage. (Make sketch).

35. Before opening the drafts, what should a fireman do?

36. Describe briefly the different kinds of forced draft and whne used.

37. Explain the importance of gage cocks.

38. Do you think mismanagement causes many boiler explosions? Why?

39. What data should be taken at a boiler trial, and at what intervals?

40. Find the diameter of the steam pipe when the total amount of steam furnished per minute is 200 pounds; the pressure is 105 pounds absolute, and the allowable velocity 5,500 feet per minute. Ans. $5\frac{1}{4}$ + inches. Use 6-inch pipe.

41. Name some general causes for boiler explosions.

42. Why does the application of high pressure injure a boiler?

43. Name three ways to prevent and remove scale.

44. Describe boiler testing by the Standard method.

45. Why is there a large amount of energy in boilers? Is it in the water or in the steam?

46. Name the principal apparatus used in boiler trials and describe their uses.

47. What impurities in feed water cause corrosion?

48. Explain the action of soda on feed water impurities.

49. The following results were obtained from a separator calorimeter test; weight of dry steam 12 pounds, weight of water separated 8 ounces, radiation loss 2 ounces. Find the quality of the steam. Ans. 3 per cent. moisture.

50. The data from a throttling calorimeter test are as follows: steam pressure 85 pounds (absolute), pressure in calorimeter 25 lbs. (absolute), and temperature in calorimeter 266.5°F. Find the quality of the steam. Ans. 1.18 per cent. moisture.

51. What is the action of kerosene oil in a boiler?

52. How is forced draft measured?

53. Find the equivalent evaporation when a boiler evaporates 1,900 pounds of water per hour; the gage pressure being 115 pounds, and the temperature of feed water 80°F. What is the horse-power of the boiler?

Ans. Equivalent evaporation 2,242 pounds. 65 H. P.

REVIEW QUESTIONS

ON THE SUBJECT OF

STEAM PUMPS.

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1. Find the pressure per square inch corresponding to a head of 187.42 feet.

2. Under what conditions should a centrifugal pump be used?

3. Describe the rotary pump.

4. If a large quantity of water is to be lifted a slight amount (for instance 20 feet) is it better to use a direct-acting pump or a centrifugal pump?

5. How many gallons per minute can be raised by a pump having a water cylinder 8 inches in diameter, 12 inches stroke, if it makes 45 double strokes per minute? Assume 6% slip.

6. What materials are used for valve discs for cold water? For hot water?

7. Which is the better form of spring for a valve, cylindrical or conical? Why?

8. Under what conditions is it better to use a plunger pump rather than the piston type?

9. A single cylinder pump is 6"x10". What should be the volume, diameter and height of the air chamber on the discharge pipe?

10. A 12"x10" duplex makes 52 double strokes per minute. What is the piston speed in feet per minute and what is the discharge in gallons?

11. A double-acting pump is to discharge 232 gallons per minute. On account of the pressure against which the pump must work, the water cylinder must be 7 inches in diameter. The allowable number of double strokes per minute is 55. What is the length of stroke? What is the piston speed?

12. Suppose a pump has a suction of 14 feet and the loss due to friction in the piping is 3 pounds per square inch. The pump is a 3″ × 10″ and the discharge is against a head of 86 feet. If the pump makes 40 double strokes per minute, what horse power is required, allowing 20% for friction ?

13. The head against which a pump works is 122 feet. If the plunger is 4 inches in diameter and the steam end 7 inches, what steam pressure must be used? Consider the plunger friction to be 75 pounds.

14. A boiler-feed pump works against a pressure of 145 pounds. It draws water from a tank located so that the lift is 16 feet. If the steam pressure at the pump is 130 pounds and steam cylinder is 8 inches in diameter, what is the diameter of the plunger ? (a) Make no allowance for friction. (b) Assume friction to be 15%.

15. Describe the setting of the valves of a duplex pump.

16. Describe the valve motion of a duplex pump.

17. Draw a diagram and locate the high-pressure cylinder, the low-pressure cylinder, the pistons, the piston rod, water cylinder, plunger, and air chamber of a tandem compound pump.

18. What means are used for connecting the shaft of a gas or steam engine to a triplex pump ?

19. How is steam cushion obtained in a pump ?

20. Why are laps added to steam valves ?

21. What should be the maximum lift for a disc valve ?

22. Explain with sketch the action of the combined forcing and lifting pump (double acting).

23. Describe the usual lost-motion device for a duplex pump. Why is it used ?

24. Where should the check valve of a suction end be placed?

25. What kind of packing is commonly used in the water-end stuffing box ?

26. If a pump slams on one stroke but not on the other, what is the probable cause ?

27. Give method of procedure in starting a compound condensing pump.

28. What is the most common cause of short stroke on one side of a duplex pump ?

29. What is meant by "duty"?

30. How may the slip be found?

31. The statement on page 42, lines 8, 9, and 10, gives the ordinary method of determining the actual from the theoretical H. P. Is it correct mathematically? What is the actual efficiency assumed in the case?

32. What size rod would you use for a 9" piston?

33. What would be the diameter of the valves for a 10" x 12" pump, if four valves were used?

34. What form of steam valve is used for direct-acting pumps? How are the valves operated?

35. What are the important points to watch in piping up a pump?

36. Where could graphite be used to advantage in pump running?